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THE TWO-FOOT REFLECTING TELESCOPE OF THE YERKES OBSERVATORY.

By G. W. RITCHEY.

THE mounting for the two-foot reflector of the Yerkes Observatory is the largest and perhaps the most important piece of work which has been done in the instrument shop of the Observatory. The telescope is mounted in the southeast dome, which was originally intended for a sixteen-inch refractor. This dome is thirty feet in diameter—somewhat larger than is needed for the reflector, though the protection of the instrument from the wind is better than it would be with a smaller dome. Since the center of motion of the telescope is low it was necessary to extend the original massive brick pier about twelve feet higher in order to bring the instrument sufficiently high with reference to the opening in the dome. A substantial observing platform or floor, twenty feet in diameter and twelve feet higher than the original floor of the tower, was also built. With the present arrangement the eyepiece or plate-holder is never more than eleven feet above the floor, and hence is always easily accessible with the aid of a suitable observing chair.

THE MIRRORS.

While the instrument is generally called the two-foot reflector, the clear aperture of the large mirror is 23½ inches, the focal length being 93 inches. The disk of glass for this mirror was made at the St. Gobain Glass Works, near Paris, for the writer, who finished the work of grinding, polishing, and figuring it, in 1896, at his own laboratory in Chicago. A high degree of accuracy of figure was obtained. Those who have attempted to figure paraboloidal mirrors of large angular aperture will appreciate the care necessary to parabolize accurately a large mirror in which the ratio of focal length to aperture is less than as four to one, as in this case.

In testing this mirror at the center of curvature while figuring it, the writer found that it was entirely unsatisfactory to employ an eyepiece in determining the focus of the successive zones, as described by Draper and Common. The difficulty was due to the great angular aperture and the consequent rapid change of curvature, especially in the outer zones. If zones of the usual width, fifteen or twenty millimeters, were used it was found that the difference of focus of the inner and outer parts of a zone was so great that the image in the eyepiece showed evidence of strong aberration; while if narrow zones, of three or four millimeters width, were used the image in the eyepiece was very indistinct, as a result of the strong diffraction effect produced by the edges of the screen. Finally it was found that very narrow zones or arcs could be used by employing the knife-edge instead of an eyepiece for determining the position of the focus; this method was found to be so accurate that, with some practice, the focus of a zone could be determined without difficulty to within 0.04 mm. Twelve zones were employed in testing, and about three month's work was devoted to the final figuring.

The reliability and accuracy of this method of testing was later demonstrated by independent tests on the stars, with fine atmospheric conditions, and also by testing in conjunction with a 24-inch plane mirror. In the latter test the artificial star is placed at the focus of the paraboloid; the rays of light are

collimated by reflection from the paraboloidal mirror, and after reflection from the large plane mirror return to the former mirror in a parallel beam, whence they are reflected to a focus very near to the artifical star. The paraboloidal mirror can thus be tested at its focus, as a whole, without the use of zones, precisely as a spherical mirror is tested at its center of curvature. Given a good plane mirror of the same size as the concave one this method is highly satisfactory in practice; the many tedious focal settings and the somewhat troublesome interpretation of the

FIG. 1.

focal readings, necessary in the zonal test, are avoided; the entire paraboloidal mirror is seen in relief, and the position and character of any errors of figure are most easily determined. The arrangement of mirrors for this test is shown in Fig. 1. In practice the artificial star is placed very slightly to one side of the axis of figure, and the reflected image is formed at the same distance on the opposite side. For convenience a small diagonal plane mirror is also used, as shown in the figure.

In this connection it may be of interest to describe briefly the method of testing used when figuring the five-inch hyperboloidal convex mirror which is employed when this telescope is used as a Cassegrain, and by the use of which an equivalent focal length of 38 feet is secured. The artificial star is now placed at the secondary focus (see Fig. 2); the diverging cone of light strikes the five-inch convex mirror, and is by it rendered more divergent, so that it fills the 23½-inch paraboloidal mirror. The rays are reflected from the latter mirror in a parallel beam,

strike the 24-inch plane mirror, return to the concave, then to the small convex and thence to a focus close beside the artificial star. By this arrangement the convex mirror is tested as a whole, at the secondary focus, without the use of zones, precisely as a concave spherical mirror is tested at its center of curvature. Assuming that the large paraboloidal and plane mirrors are finished, any errors of figure which are seen by means of the knife-edge or other tests are due to the convex mirror, and their position and character can be readily determined. The work of

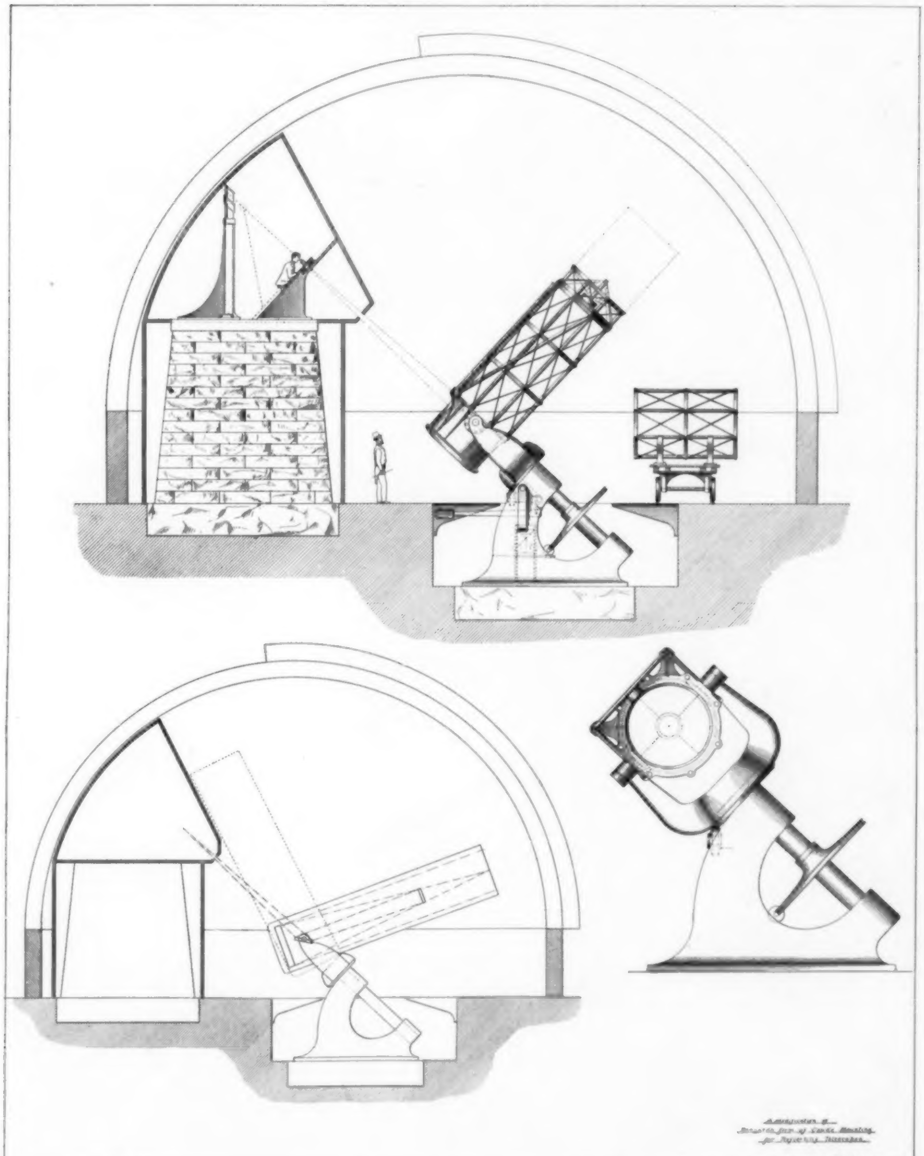
FIG. 2.

grinding and figuring the convex mirror was done, under the writer's direction, by Mr. F. G. Pease, assistant in the optical laboratory.

THE MOUNTING.

Before describing the mounting a brief historical account may not be out of place. While figuring the large mirror the writer designed a complete mounting for the instrument, in which were embodied the plans suggested by many years of experience with reflecting telescopes and in astronomical photography, and of study of existing mountings. In this design a short massive fork was to be used at the upper end of the polar axis, between the two arms of which fork the tube turned on trunnions for movement in declination. The short strong end of the tube below the declination trunnions contained the large mirror and its cell, which served to balance the skeleton tube above. In this form of mounting no dead-weight in counterpoises is required, and a part of the metal and weight, which in many other forms are necessary for counterpoises, can here be used to advantage

PLATE IX.



DESIGN FOR THE MOUNTING OF A FIVE-FOOT REFLECTING TELESCOPE.

in giving massiveness and extreme rigidity to those parts upon which the stability of the mounting, so necessary in astronomical photography, depends. Included also in this design was the writer's plan of support for the large mirror in its cell (described in this JOURNAL for February, 1897), by which an effective flotation system of support and very great stability of position of the mirror are at once secured. In all essential features, with one exception, the plan of mounting just described is similar to that which the writer has used in designing the mounting for the five-foot reflector, the mirror for which is nearly finished. Several diagrams illustrating the latter design are shown in Plate IX. The exception mentioned is this: The plan for the five-foot is adapted to include, if desired, the *coudè* arrangement of mirrors which was suggested by Mr. Ranyard to Professor Hale in 1894. This arrangement will be readily understood, without description, by reference to the plate.

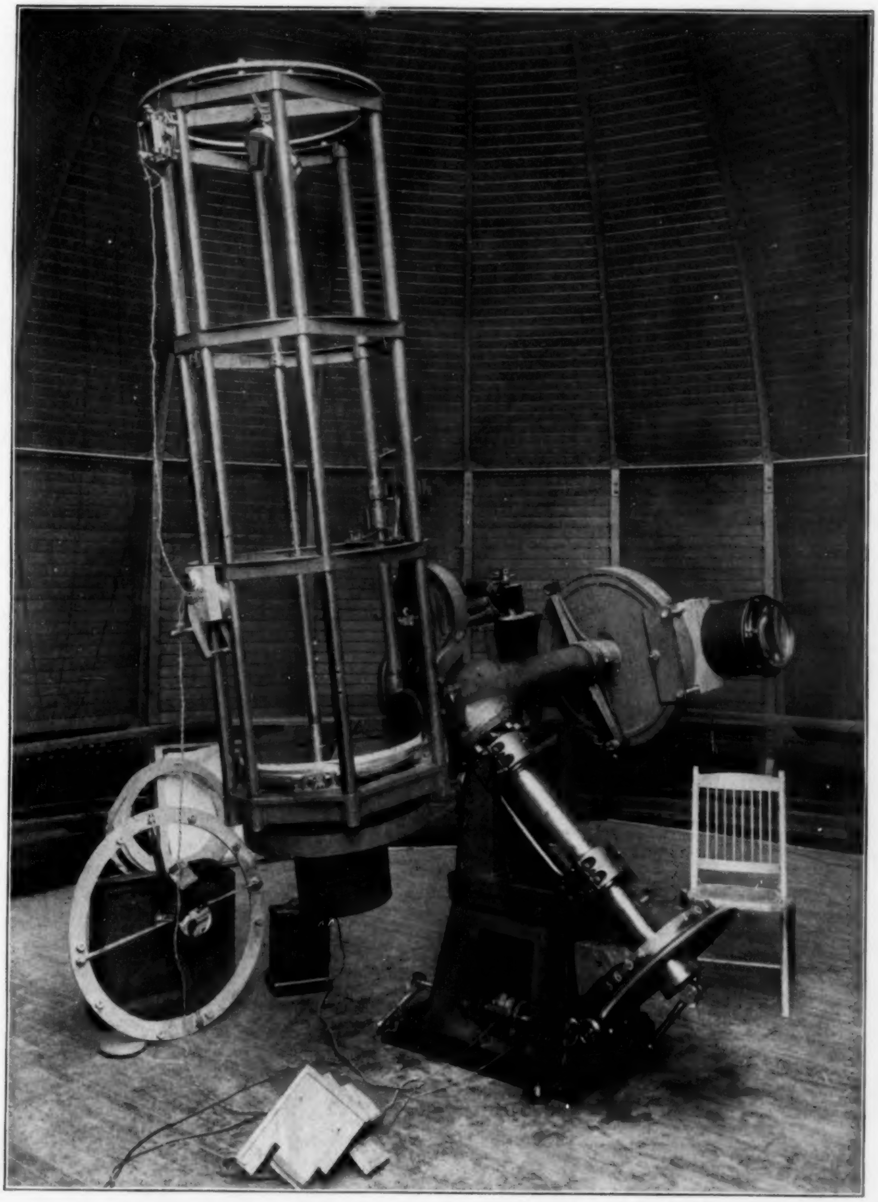
To return to the subject of the two-foot mounting. For some time after the mirror was finished the instrument shop of the Observatory (which does not include the optical laboratory) was in charge of Professor Wadsworth, who designed a two-foot mounting of very different form, the construction of which was begun under his supervision. When Professor Wadsworth left this Observatory, the writer was placed in charge of the instrument shop, and work on the reflector mounting, which had been long interrupted, was resumed. The heavy base parts, already partially finished, which included the short column, equatorial head, and polar and declination axes, were retained. From the writer's designs the remainder of the mounting was constructed, including the skeleton tube, with interchangeable ends, driving-clock, clock connections, mirror-support, slow-motions, double-slide plate carrier, nine-inch Cassegrain guiding telescope, and the spectroscope support.

As will be seen by reference to Plate X, the arrangement of the axes is similar to that used in the German type of equatorial mounting. The design is such that, while it is possible to reverse the instrument, which is often desirable and convenient,

reversal is not necessary, as the end of the tube below the declination axis is so short that it will pass the column without obstruction for all declinations. Long exposure photographs can therefore be started four or five hours east of the meridian, and continued without interruption for eight or ten hours, when desired, as is the case with the fork mounting shown in Plate IX.

On account of the great importance of an effective anti-friction device for the polar axis, attention should be called to the action of the single anti-friction roller used by Professor Wadsworth in this mounting, which is intended to reduce friction at the upper bearing of the polar axis and at the same time to relieve the end-thrust. This plan was originally suggested, I think, by Dr. Gill. The cylindrical roller, with its axis horizontal and its surface slightly crowning, is mounted on a heavily-weighted lever so as to press vertically upward against the conical surface of an enlargement or head at the upper end of the polar axis. This is shown in Plate X. The device is a beautiful one at first sight, but presents serious difficulties in practice. Its action was not smooth and uniform, but gave rise to sharp jerks in driving, which occurred at nearly regular intervals of a few seconds. Part of the trouble was due to the necessary slight slipping of the *cylindrical* roller (though with slightly crowning surface) on the *conical* surface against which it bears; this was shown by the fact that the jumping was improved, but not entirely cured, by turning the surface of the roller much more crowning, so that the line of contact is very short. The manner in which the bearing or axis of the roller is worn indicates that there is also a very strong oblique pressure communicated to the roller by the conical surface; the bad effect of this could be reduced by making the axis or bearing of the roller much longer. The slipping mentioned above could be cured by the use of two conical surfaces having the same angle. A well-made anti-friction end-thrust bearing for the polar axis is most desirable in any case; there is none in the present instrument, and the design of the base parts is such that it would be difficult to introduce one. The trouble in the present case is

PLATE X.



TWO-FOOT REFLECTOR OF THE YERKES OBSERVATORY.

aggravated by the small size of the friction roller and by the great weight of the moving parts; this amounts to about 2,500 pounds, almost exactly one-half of which is due to the counterpoises which, in this particular form of mounting, are necessary on the short lower end of the tube and on the opposite end of the declination axis.

Smooth driving is at present secured by allowing the roller to carry only a small part of the weight of the moving parts, and by attaching sufficient weight to the west side of the mounting to cause the instrument to rotate easily in that direction; unnecessary wear of the clock and the clock connections is thus avoided. This makeshift is, of course, unsatisfactory and somewhat inconvenient in practice; nevertheless good results are obtained.

It must not be supposed that the difficulties just described are at all necessary, or that they are peculiar to the reflecting telescope. On account principally of the very powerful driving clock and clock connections, which are described below, the smoothness of driving of the two-foot reflector, as at present used, is decidedly better than that of the forty-inch refractor; this is best seen when the instrument is used as a Cassegrain, with an equivalent focal length of thirty-eight feet.

THE DRIVING MECHANISM.

The driving-clock, part of which can be seen inside the column in the illustration, is similar in general plan to that of the forty-inch refractor, and is one-fourth the size of the latter, the governor making two revolutions per second instead of one, as in the larger instrument. The governor balls weigh about seven pounds each, and all parts of the clock are proportionally heavy and strong. All of the clock gears were cut in our instrument shop, on the Brown & Sharpe milling machine, by Mr. Johannesen. The winding drum is provided with a maintaining device. Winding is at present done by hand, and must be attended to every two hours.

The connections between the driving-clock and the large

worm gear which rotates the polar axis are short and very large and strong; they include a differential gear arrangement for slow motion in right ascension.

The driving-worm and worm gear were ground together for two hundred hours with fine grades of emery (such as are used in optical work) and oil, and the smoothing was finished with polishing rouge and oil. This was done just before the instrument was set up, and with all of the involved parts in their final positions on the mounting. To this the extraordinary smoothness of driving is largely due.

THE MIRROR SUPPORT.

One of the most troublesome difficulties which the writer had to meet in completing the design for the mounting was to find room for an efficient support system for the large mirror.

The writer's original plan of support, referred to above, could not be used on account of the shape of the large casting behind the mirror, which forms a part of the declination axis and which had already been partially finished. The plan of support finally adopted is as follows: The mirror rests upon three very rigid cast-iron plates, ten inches in diameter, the upper surfaces of which are ground to fit the back of the mirror. One thickness of writing-paper is placed between each iron plate and the glass. Each plate is supported at its center on a strong ball-and-socket joint. The three balls form the upper end of the three large adjusting screws which extend through the heavy back casting, and by which the mirror is adjusted for collimation. The edge-support adopted consists of four strong steel bands, each of which is in contact with nearly one-half the circumference of the mirror; two opposite bands are just above the middle of the edge of the mirror; the other two, ninety degrees from the first, are just below this plane. In addition, four long rigid arcs of cast-iron are used to give greater stability of position laterally; two of these are bolted down to the large casting behind the mirror; the other two are held against the edge of the mirror by weak springs.

Although far from perfect in principle, the support system just described is very satisfactory in practice, for a mirror of this size. The mirror is supported without deformation, and no appreciable change of collimation can be detected as the telescope is turned in widely differing positions; this is determined by the use of a modification of Stoney's method of collimation.

THE SKELETON TUBE.

The skeleton tube is about seven feet long, and is constructed of eight two-inch steel tubes, which are connected by three strong light rings of cast aluminum. The rings are driven on the tubes, and each junction is tightly clamped with two strong screws, as can be seen in the illustration. Provision was made for diagonal tension rods, but the frame is so extremely rigid without them that they have not been added.

For various kinds of work three distinct ends or attachments are now used which can be quickly connected to the upper end of the skeleton tube. One attachment consists of a strong cast-aluminum ring which carries, by means of four thin wide bands of steel, the diagonal plane mirror and its supports. This attachment is employed when the telescope is used with the double-slide plate-holder for direct photography at the first focus. A second attachment is a similar ring carrying the convex (Cassegrain) mirror and its supports; this is used when the instrument is employed for spectroscopic work; it will also be used with the double-slide plate-carrier at the secondary focus for the direct photography of objects requiring great scale, and for visual and photometric observations. The third attachment consists of a short light frame which supports a plate-holder at the direct focus of the large mirror, for photographing without the intervention of the diagonal plane mirror; this attachment has been used but little thus far, but can be employed to advantage in direct photographic work for which the double-slide plate-carrier is not available, such as the photography of comets.

For such work a nine-inch guiding telescope has been provided. This is a reflector, of the Cassegrain form, with equivalent focal length of fifteen feet. The advantages of using such

a reflector for this purpose are apparent: the heavy parts are all carried by the massive parts of the mounting instead of by the light skeleton tube, and the eyepiece is always in a convenient position for guiding. The nine-inch concave mirror and all of the metal parts for the guiding telescope have been finished, but the 2¾-inch convex mirror has not yet been completely figured; this telescope is, therefore, not attached to the mounting at present, and is not shown in the illustration; it is of course not necessary when the double-slide plate-carrier is used.

THE SPECTROSCOPE SUPPORT.

The method of attaching the spectroscope, which weighs about one hundred pounds, to the telescope mounting will be best understood by reference to Plate X. It is carried by a strong iron ring with two heavy arms, which are bolted to the casting supporting the large mirror and the skeleton tube. The spectroscope is permanently attached to the mounting, and need not be removed to allow other kinds of work to be done with the telescope, as is the case with the spectroscopes which are used with the forty-inch refractor. The suggestion of this very convenient arrangement of the spectroscope is due to Professor Wadsworth.

DOUBLE-SLIDE PLATE-CARRIER.

The double-slide plate-carrier used with the two-foot reflector is the same which was used in the writer's first experiments in photographing with the forty-inch telescope with a color-screen. In the latter work a large sliding plate-carrier taking 8 × 10-inch plates is now used. The smaller one takes 3¼ × 4¼-inch plates, and the field photographed is three inches square, which corresponds, in the two-foot reflector, to a portion of the sky about two degrees square. This invaluable attachment to a photographic telescope was first suggested, I think, by Dr. Common, and is described by him in *Monthly Notices*, **49**, 297. The present instrument or attachment is briefly described by the writer in this JOURNAL, **12**, 355, 1900.[1]

[1] Plate X shows also a ten-inch portrait lens, temporarily attached to the declination circle.

RESULTS.

In practice the combination of (1) stability of position of mirror; (2) smoothness of clock-driving; (3) rigidity of skeleton tube; and (4) delicacy of following made possible by the use of the sliding plate-carrier, is so effective that when atmospheric conditions are good the image of the guiding star in the eyepiece of the plate-carrier does not wander by so much as one one-hundredth part of a millimeter, during an exposure of three or four hours. The accuracy with which the star images are kept immovable on the photographic plate is nearly as great, as is shown by the photographs. In the best negatives, with four hours' exposure, the images of the smaller stars near the center of the field are about 2″ in diameter. Double stars of 2″.5 distance are sharply separated and those of less than 2″ distance, corresponding to about 0.02 mm on the photographic plate, are measurable. When the focal length is taken into account, these results are not surpassed by those obtained with the best photographic refractors. It is of course only when atmospheric conditions are very fine that such results can be obtained. With such conditions stars fainter than the seventeenth magnitude (the visual limit of the forty-inch refractor), are photographed with forty-five minutes' exposure.

No greater mistake could be made than to suppose that the finest atmospheric conditions are unnecessary to secure the best results in photography of the nebulæ. With such conditions the photographs show that these objects are not diffused hazy masses, but that their structure is most complicated, often consisting of exquisitely fine filaments and delicate narrow rifts. In these photographs the intersections of such filaments and rifts can be set upon in the measuring machine with almost the same accuracy that is possible in the case of star images. Changes of form of the nebulæ, if such occur, could be detected with certainty by such photographs. There can be no question in regard to the superiority of the photographic method over the visual for the detection of such changes, and for the study of nebulæ in general. The greater part of the fine structure

referred to cannot be seen directly with any telescope; this is due partly to the fact that it is usually too faint to affect the eye, and partly to the fact that in the photographs the contrast between light and dark parts can be greatly exaggerated by proper development.

Plate VIII is from a photograph of the Great Nebula in *Andromeda*, obtained by the writer with the two-foot reflector on the night of September 18, 1901, with an exposure of four hours. The aperture was in this case reduced to eighteen inches, in order that good definition might be secured over a larger field than is well covered when the full aperture is used. In the original negative the fine spiral structure is visible almost to the center of the nebula, and the stellar nucleus is distinctly seen. Sharply defined narrow rifts and dark holes are shown on all of the negatives near the center; no trace of these can be detected visually with any telescope. The enlargement as compared with the original negative is 4.5 diameters.

The photograph of the nebula *N. G. C.* 6992 in *Cygnus* (Plate XI) was taken on the night of October 5, 1901, with an exposure of three hours. The enlargement from the original negative is in this case about 3.5 diameters. Some idea of the wonderful filamentous structure of this nebula can be obtained from the half-tone illustration, but, as in the case of the illustration of the *Andromeda* nebula, an enlargement fully four times as great would be necessary in order that the fine details shown on the negative might be satisfactorily reproduced in the half-tone plate. In making these photographs the most rapid plates obtainable are used, and the granularity of the negatives is kept extremely fine by careful treatment in development.

CONCLUSIONS.

The experience gained in the construction and use of this instrument, and the results obtained with it, are most interesting to the writer as showing the possibilities of the future great reflector in astronomical photography. It has often been asserted by prominent writers on the subject that a large reflector

PLATE XI.

S.

N.

NEBULA *N. G. C.* 6992, IN *CYGNUS.*

PHOTOGRAPHED WITH THE TWO-FOOT REFLECTOR OF THE YERKES OBSERVATORY BY G. W. RITCHEY.

is necessarily inferior to a large refractor in many vital points, such as permanence of optical qualities, freedom from injurious flexure of optical parts, permanence of adjustments or collimation of optical parts, rigidity and stability of the mounting, and convenience in use. Unfortunately for astronomical science the experience with many of the large reflecting telescopes which have been built has been such as to give apparent support to this view. Even the experience of the late Professor Keeler with the Crossley reflector, with which, in spite of the great difficulties described by him, he obtained such superb results, was such that one might easily suppose these difficulties to be unavoidable in a great reflector.

Nothing could be further from the truth. A large mirror can without difficulty be mounted in its cell with all of the stability of position possible in the case of a large lens, and with far greater stability of position than is now attained with such lenses. While the effect of flexure is more serious in the case of a large mirror than in that of a lens, such a mirror can be made very thick (this is objectionable in the case of a lens on account of greater absorption), and can be supported at its back by a flotation system inexpensive in construction and of any required degree of efficiency; twelve supporting plates or any larger number can be used, each of which carries its own proportion of the weight of the glass. Such a support in no way interferes with the stability of position of the mirror, above referred to.

With reference to permanence of optical qualities, permanence of adjustments, difficulty of silvering, etc., it should be stated that the re-silvering of large mirrors is not at present a difficult operation. While the shape of the heavy casting behind the large mirror in the two-foot reflector is such that the mirror can be removed from the mounting for re-silvering only by lifting it out through the sides or end of the skeleton tube, yet this mirror and the diagonal flat have been removed from the mounting, re-silvered, burnished and replaced without sensibly disturbing the adjustments and collimation, as shown by very

sensitive tests, and without changing the position of the focal plane by so much as 0.05 mm, the interval which is used in making the trial photographs for focus. Three or four hours are required for the entire operation, including the preparation of the silvering solutions. In the form of reflector mounting shown in Plate IX the large mirror can be removed from the telescope with ease and quickness, and without removing it from its cell or its supports it can be re-silvered and replaced in the telescope without the slightest appreciable disturbance of adjustments, collimation, etc. With a five-foot mirror this could be done in eight or ten hours — between morning and evening of any day.

With reference to permanence of focal length the following facts may be stated. In making trial photographs for focus of the two-foot reflector it is found that the position of the focus can be determined to within 0.05 mm, when atmospheric conditions are good. A careful record of the focal length of the mirror for a range of temperature of about 28° C. has been kept. The apparent differences of focus at the plate-holder on different nights are found to be such as are exactly accounted for, in direction and amount, by the expansion and contraction of the steel tubes of the skeleton framework, following temperature changes. Since the change in the length of the steel framework for the range of temperature mentioned is about 0.75mm and the focus determinations are accurate to within 0.05mm, it is certain that the actual change in the focal length of the mirror for this range of temperature is so small that it cannot be detected.

No changes of focus during long exposures, such as are described by Professor Keeler in the case of the Crossley reflector, and which he attributes to the effect of flexure in the instrument, can be detected in the two-foot reflector, though they have been carefully watched for.

In the case of the forty-inch refractor, the absolute focal length of the objective is shortened by a given fall of temperature, by an amount almost exactly twice that of the contraction of the tube. Thus, for a fall of 28° C. the focal length

of the objective is shortened by about 12 mm, while the contraction of the tube amounts to 6.25 mm. The accuracy with which, with the best atmospheric conditions, the focus of the forty-inch refractor can be determined by trial photographs for focus, is about one-fifth as great as in the case of the two-foot reflector. This is in good accord with the ratio of the angular apertures of the two instruments.

With regard to the question of the rigidity and stability of the mounting of a reflecting telescope, it will be seen, by again referring to Plate IX, that all of the heavy parts of such a mounting, including the parts which carry the large mirror, can be made extremely compact, massive, and rigid. The skeleton tube also can be made excessively rigid; it is very short as compared with the tube of a refractor of the same aperture; and it has no great weight to carry at its extremity, as is necessary in the case of the refractor. How unreasonable then is the common assertion that the reflector mounting is necessarily clumsy, unstable, and subject to large flexures.

The following considerations may serve to illustrate the convenience and economy of the reflector.

One of the most important points to be decided in undertaking the construction of a reflecting telescope for photographic work is in regard to the ratio of focal length to aperture to be adopted. As already stated, this ratio in the case of the two-foot reflector is nearly as four to one. With such a ratio the light-concentration is very great, and faint nebulæ can be photographed with proportionally short exposures. The advantages of such a large angular aperture are strikingly shown in the photography of such objects as the excessively faint nebula about *Nova Persei*,[1] and in photographing the faint spiral nebulae, the great majority of which are small. But the field which is sharply covered when this angular aperture is used is necessarily small. In photographing such large objects as the *Andromeda* nebula and the *Pleiades*, the aperture of this telescope is usually reduced to twenty or eighteen inches; the field which

[1] ASTROPHYSICAL JOURNAL, 14, 167, 1901.

is well covered is thereby much increased in size, while the necessary exposures are of course lengthened. In the five-foot reflector, a ratio of five to one was adopted.

Experience in figuring and testing rigorously the convex mirror for the two-foot, as described earlier in this article, and its actual use in the telescope, have led to the belief that the enlarged images obtained by the addition of the Cassegrain mirror are nearly or quite as perfect as can be obtained by the direct use of a large mirror of great focal length. Taking the five-foot reflector of twenty-five feet focal length as an illustration, it will be possible to use this great instrument at its principal focus for the photography of such objects as the large and faint nebulæ, and, by the addition of a convex mirror of about eighteen inches diameter, amplifying three or four times, an equivalent focal length of seventy-five or one hundred feet can be secured, for the photography of objects requiring great scale, such as the dense star clusters and annular and planetary nebulæ. For all kinds of work perfect achromatism and the high photographic efficiency of the reflector are retained. The skeleton tube in this instrument will be a little over six feet in diameter, and its length will not be greater than eighteen feet for any of the work mentioned. The internal diameter of the dome need not be greater than forty-five feet.

But however perfect the mirrors, and however carefully designed the mounting of the future great reflector, no improvement in the results in any degree proportional to the increase of size can be expected without a fine climate, with good atmospheric conditions, in which to use it.

The results obtained with the two-foot reflector show that very fine atmospheric conditions are necessary for the best results even in the photography of nebulæ, while for the photography of such objects as the dense globular star clusters the requirements are, if possible, even more exacting. It is interesting to think of the photographic results which could be obtained with a properly mounted great reflector in such a climate and in such atmospheric conditions as prevail in

easily accessible parts of our own country, notably in California.

I wish to express my indebtedness to Professor Hale and Mr. Ellerman for valuable suggestions: to Mr. Johannesen, the Observatory instrument maker, and to Mr. Neidhold, the former machinist, for the excellent workmanship of the mounting of the two-foot reflector; and to Mr. Pease for most able and enthusiastic assistance in nearly all of the direct photographic work with the instrument.

YERKES OBSERVATORY,
UNIVERSITY OF CHICAGO.
October 25, 1901.

ON THE TEMPERATURE AND COMPOSITION OF THE ATMOSPHERES OF THE PLANETS AND THE SUN.[1]

By E. ROGOVSKY.

IT is shown in aerostatics that the density ρ_r of any gas at the distance r from the center of the Earth, or other solid or liquid body surrounded by a gaseous atmosphere, may be expressed as follows:

$$\rho_r = \rho e^{-\frac{ag}{k}\left(1-\frac{a}{r}\right)} \qquad (1)$$

where ρ is the density of this gas at the surface of the body in question—for instance, the Earth; e is the base of the Naperian logarithms, a is the radius of the body, g is the acceleration due to the attraction at its surface, k is the coefficient in the formula

$$p = k\rho \qquad (2)$$

where p is the pressure of the gas. This coefficient, it is known, depends on the temperature, and $k=k_0(1+\alpha t)$, where t is the temperature of the gas, k_0 the value of k at $t=0°$, and α the coefficient of thermal expansion of gas, or $k=\alpha k_0 T$, where T is the absolute temperature $=t+273°$. The kinetic theory of gases gives a formula identical with (1),[2] but $k=\frac{V^2}{3}$, where V^2 is the mean of the squares of the velocities of all the molecules of a given gas.

As we know, gases may expand infinitely. This follows from experiments, the results of which may be expressed by Boyle's formula, or that of van der Waals or Clausius, and it is also a necessary consequence of Maxwell's kinetic theory of

[1] Revised and translated by the author from *Transactions of the Russian Astronomical Society*, Part VII, 1898, pp. 10–34, and VIII, 1899, pp. 32–45.

[2] E. ROGOVSKY, "On the Constitution of the Earth's Atmosphere and General Laws of the Theory of Gases," *Journ. of Russ. Phys.-Chem. Soc.*, **16**, 32, 1884.

gases,[1] which assumes that the molecules of gases have all possible, and, consequently, very high, velocities. The atmospheres of the planets and Sun are, therefore, unlimited, and pass gradually into the cosmical or interplanetary medium.

Putting in (1) $r = \infty$, we find

$$\rho_\infty = \rho e^{-\frac{ag}{k}}, \tag{3}$$

i. e., the partial density of the given gas in this medium. According to the kinetic theory of gases, this medium is composed of molecules moving in orbits having the form of a parabola or hyperbola.[2]

Taking another body, the density of the same gas in the interplanetary medium will be found

$$\rho_\infty = \rho_1 e^{-\frac{a_1 g_1}{k_1}}. \tag{4}$$

The quantities (3) and (4), being the density of the same gas in the same medium, are equal to each other, and, consequently, when both atmospheres are in equilibrium,

$$\rho e^{-\frac{ag}{k}} = \rho_1 e^{-\frac{a_1 g_1}{k_1}}, \tag{5}$$

or

$$\frac{a_1 g_1}{k_1} - \frac{ag}{k} = \log \rho_1 - \log \rho. \tag{6}$$

The temperature of the celestial medium or space has no sensible influence on the distribution of the gases among the atmospheres of the Sun and planets:[3] its increase or decrease causes

[1] J. C. MAXWELL, "Illustration of the Dynamical Theory of Gases," *Phil. Mag.*, 4th ser., **19**, 19–32, 1860; **35**, 129–145, 185–217, 1868. See also, for instance, O. E. MEYER, *Die kinetische Theorie der Gase*, 2. Aufl. 1897–1899 (an English translation exists); L. BOLTZMANN, *Vorlesungen über Gastheorie*, I Th. 1895, II Th. 1898; H. W. WATSON, *A Treatise on the Kinetic Theory of Gases*, 1893; S. H. BURBURY, *A Treatise on the Kinetic Theory of Gases*, 1899: or any course on thermodynamics, for instance, those of RÜHLMANN, CLAUSIUS, KIRCHHOFF, etc.

[2] E. ROGOVSKY, *loc. cit.*, pp. 35, 534. In this paper the number of both kinds of molecules is determined.

[3] The distribution of the gases among the planets is also not affected by their mutual attraction and their movements, owing to their very great mutual distances in comparison with the size of those parts of their atmospheres which have a perceptible density.

only the equal expansion or contraction of all the atmospheres without affecting their relative density. The distribution of gases and the relative density of the atmospheres upon the planets depend only on their own internal heat and that produced by the Sun's radiation. The sum of these two is the amount by which the temperature of the atmospheres of the planets exceeds that of the interplanetary or celestial medium, and, therefore, instead of k and k_1 in the foregoing formula, we may write ak_0T and ak_0T_1, if T and T_1 are the differences between the mean temperatures of the atmospheres of the bodies and the temperature of the celestial space or medium. We have

$$\frac{a_1g_1}{T_1} - \frac{ag}{T} = ak_0 (\log \rho_1 - \log \rho), \tag{7}$$

or

$$\frac{a_1g_1T}{agT_1} - 1 = \frac{ak_0T}{ag} (\log \rho_1 - \log \rho). \tag{8}$$

Attributing the letters without the subscript to the Earth, $\frac{ak_0T}{ag}$ is about 0.00031; assuming, moreover, $\log \frac{\rho_1}{\rho}$ to be small, which is admissible on account of the small difference of the densities of the Sun and planets (see Table II), the second member of equation (8) may be neglected.

Thus, we have

$$\frac{T_1}{T} = \frac{a_1g_1}{ag}, \tag{9}$$

or $\frac{ag}{T}$ is constant for all the planets.

We can give to formula (9) a simpler form, since

$$g = f\frac{m}{a^2} \quad \text{and} \quad g_1 = f\frac{m_1}{a_1^2}$$

where m and m_1 are the masses of two bodies, and f is the constant of gravitation.

Thus,

$$\frac{T_1}{T} = \frac{\frac{m_1}{a_1}}{\frac{m}{a}}$$

or
$$\frac{T_1}{T} = \frac{U_1}{U},$$ [1]

U and U_1 expressing the values of the potential function of gravitation at the surfaces of the bodies T and T_1, the differences between the mean temperatures of their atmospheres and that of the celestial medium. But it is evident that they also represent the differences between the mean temperatures at the surface of the bodies and that of the celestial medium or space.

The density of the interplanetary medium is given in formula (3). It is clear, the greater $k = \frac{V^2}{3}$, *i. e.*, the greater the velocity of the molecules of the gas, or, in other words, the smaller its atomic weight, the more slowly its density changes in the neighborhood of the celestial body; consequently the heavier gases are more condensed at the surface of the bodies; on the contrary, in the interplanetary medium the lighter gases are found in larger quantity. Putting the density of the air at the Earth's surface as unity, and the mean absolute temperature of its atmosphere as 209°.5 (= −63°.5 C.),[2] the density of air considered as simple substance in the celestial medium is about 10^{-450}, that of oxygen separately, 10^{-500}, of nitrogen, 10^{-440}. The ratio of the last two equals 10^{-60}. These densities are so small that the medium can have no influence on the motion of the heavenly bodies.

Since the molecules of this medium are in motion, it has a certain temperature, and by the "temperature of celestial space" must be understood that of the medium which fills this space. The atmospheres of the planets, therefore, being composed of the molecules of this medium, also possess its temperature; but, besides that, there are yet other sources of heat; because every planet has its own internal heat, and also receives heat from the Sun by radiation. According to the theory of Kant and

[1] E. ROGOVSKY, "On the Temperature of the Celestial Bodies," *Journ. of the Russ. Phys.-Chem. Soc.*, 17, 314–325, 1885; *Fortschr. d. Physik*, 41, 3. Abth., 1577, 1885; *Beiblätter zu Wiedemann's Ann. d. Phys. und Chem.*, 11, 64, 1885. The formulae are the same, but the numerical results there given are not admissible.

[2] See p. 240.

Laplace, the celestial bodies themselves may be regarded as having been produced by the condensation of the celestial medium. But every condensation of matter develops heat, and it is the cause of the internal heat of the celestial bodies. Being expended by degrees through radiation, this heat, nevertheless, exists at the present time within them, as is shown, not only by the high temperature of the Sun and stars, but also by the heat of the central mass of the Earth. In the first stages of the evolution of the body which is in a state of gas, the heat produced by condensation is greater than that lost by radiation, as shown by A. Ritter,[1] and, therefore, its temperature gradually increases; but when a part of its substance passes to the liquid or solid state, *i. e.*, forms a liquid or solid nucleus, the quantity of heat developed by contraction of this nucleus and its gaseous atmosphere may become less than that lost by radiation, because the radiation of solid and liquid bodies at the same temperature is greater than that of gaseous bodies.[2] Accordingly, the celestial body then begins to cool. We cannot say in what stage of development the Sun is at the present time,[3] but the Earth and planets are in that of cooling. Some part of this heat, as has been said, is, nevertheless, still retained by the Earth as well as by the planets, and may be called their "own heat," and, as we

[1] A. RITTER, "Untersuchungen über die Höhe der Atmosphäre und die Constitution gasförmiger Weltkörper," *Wied. Ann.*, **5**, 554, 1878. See also ASTROPHYSICAL JOURNAL, **8**, 293, 1898.

[2] F. ROSSETTI, see p. 246.

[3] If we suppose that the temperature of the Sun at the present time is still increasing, or, at least, has been increasing until now, the glacial period of the Earth may be easily accounted for. Formerly, the Earth had a high temperature of its own, but received a lesser quantity of heat from the Sun than now: its climate was then warmer and more uniform than at present; on cooling gradually, the Earth's surface attained such a temperature as caused a great part of the surface of its northern and southern hemispheres to be covered with ice; but the Sun's radiation increasing, the glaciers melted, and the climatic conditions became as they are now. In a word, the temperature of the Earth's surface is a function of two quantities: one decreasing (the Earth's own heat), and the other increasing (the Sun's radiation), and, consequently, there may be a minimum, and this minimum was the glacial period, which, as shown by recent investigations, for instance, those of Luigi de Marchi (Report of G. SCHIAPARELLI, *Meteorolog. Zeitschr.*, **30**, 130–136, 1895) was not local, but general for the whole Earth. (See also M. NEUMAYR, *Erdgeschichte.*)

shall see, can be of very great amount on the large planets, *Jupiter, Saturn*, and others.[1] This heat is retained principally in their nuclei, and the atmospheres of the planets receive it from them.

The other part of the heat of the atmospheres of the planets is received from the Sun.

Thus, their temperature has had three sources, and is, as it were, composed of three temperatures: that of the celestial medium, that produced by their condensation (their own heat), and, lastly, that produced by solar radiation.

Pouillet found, by means of his actinometric measurements, that the temperature of the celestial, or interplanetary, medium is 142° C. below zero (from −175° to −115° C.)[2] The source of this heat he ascribes to the radiation of the stars. Such a supposition is, no doubt, erroneous, for the ratio of the heat emitted by the stars to that emitted by the Sun must be of the same order as the ratio of their light, *i. e.*, very small. But the faultiness of the supposition does not affect his measurements. We assume that the radiation of the heavens in Pouillet's measurements is emitted by the upper strata of our atmosphere, identified by us with the celestial medium, and −142° C. is the temperature of this medium. The assumption that its temperature is absolute zero is groundless: it is inadmissible that the molecules of the gases of the interplanetary medium should be motionless. Later experiments by Froelich completely confirmed Pouillet's results, viz., he found that the temperature of celestial space was −131° on August 17, and −127° on September 23.[3] Consequently, we assume that the temperature of

[1] See pp. 247–249, below.

[2] POUILLET, "Mémoire sur la chaleur solaire, sur les pouvoirs rayonnants et absorbants de l'air atmosphérique, et sur la température de l'espace," *Comptes Rendus*, 7, 24–65, 1838.

[3] O. FRÖHLICH, Ueber Himmelswärme, etc.," *Pogg. Ann. Ergänzungs.* **8**, 664–669, 1878. On the other hand, Professor D. Mendelejeff found from the observations of Glaisher that the temperature of the upper strata of the Earth's atmosphere is about −36° C. (D. MENDELEJEFF, *Journ. of the Russ. Phys.-Chem. Soc.*, 7, 260–265, 1875); but recent ascents of free balloons refute it; much lower temperatures were observed, for

celestial space is -142° C., according to Pouillet, although, perhaps, Pouillet's calculations must be revised and harmonized with Stefan's law; but the correction will principally affect the Sun's temperature; that of celestial space cannot be appreciably modified by it.

The mean temperature of the surface of the Earth may be assumed to be $+15^\circ$ C.,[1] and, thus, the mean temperature of the Earth's atmosphere is $\frac{-142+15}{2} = -63^\circ.5$ C., *i. e.*, $78^\circ.5$ C. above that of celestial space. Multiplying this number according to formula (10) by the ratio $\frac{U_1}{U}$ of the potential functions of gravitation at the surfaces of the body in question and the Earth given in the second column of the following table, and adding to the results -142°, *i. e.*, the temperature of the celestial medium, we can easily obtain the mean temperatures of the atmospheres of all the bodies of the solar system. These temperatures (θ_1)

instance, on the aerostat which was started from Paris on February 18, 1897, the temperature -66° C. was registered at 15,000m, and on that from St. Petersburg, even -75° C. at 11,000 meters. Ekholm, from the ascents of balloons, finds that the temperature at the height of 347,000m must be equal to absolute zero (-273° C.). (EKHOLM, *Meteorol. Zeitschr.* **31**, 480, 1896; *Wildermann's Jahrb. der Naturwissensch.*, **12**, 262, 1897), but we have seen that this is impossible. Recently Guillaume ("La température de l'espace," *La Nature*, **24**, Series 2, 210–211, 234, 1896) assuming that the temperature of celestial space is that of a perfectly black ball of very small size placed in this space, concludes that the temperature at an infinite distance from the Sun should be $-267^\circ.4$ C. The absolute temperature, according to Stefan's law, should be inversely proportional to the square root of the distance from the Sun, and should be, at the distance of

Mercury	$+156^\circ$ C.	*Jupiter*	-49° C.
Venus	$+94$	*Saturn*	-80
Earth	$+65$	*Uranus*	-102
Mars	$+32$	*Neptune*	-132

the effective temperature of the Sun being $+6,000^\circ$ C. But it is not possible that the temperature at the boundary of the Earth's atmosphere should be $+65^\circ$ C., and consequently, these figures cannot express the actual temperature in celestial space—especially since they are based on the hypothesis that the celestial medium has no heat of its own.

[1] Dove found on the average $+11^\circ.7$ R. $= 14^\circ.6$ C. (E. E. SCHMID, *Lehrbuch der Meteorologie*, 1869, p. 408); Forbes, $+15^\circ.6$, and Spitaler, $+15^\circ.1$ C. (W. PRECHT, "Neue Normaltemperaturen," *Meteorol. Zeitschr.*, **29**, 81–90, 1894.

are given in column 3 of the table. The mean temperatures of the surfaces of the same bodies (t_1) are given in column 7; they have been obtained by adding 142° to twice the figures of column 3. I would point out that in both these columns the complete temperatures of the planets are given, *i. e.*, taking into consideration heating by the Sun.

But the Sun's radiation chiefly affects the lower strata of the planetary atmospheres, as is proved by the more rapid increase of temperature on approaching the Earth's surface.[1] On this account, the mean temperature of the Earth's atmosphere found above is too high, and, therefore, the mean temperatures (θ_1) of the atmospheres of the planets given in the third column of the table are also higher than occurs in reality; they are, indeed, the highest limit of these temperatures. On the contrary, if we entirely neglect the influence of solar radiation, we shall find these temperatures to be below the true values. According to Pouillet, if the surface of the Earth were not heated by the Sun, its temperature would be —89° C.[2] This value, in all probability, is near to the truth, for a temperature of $-69^\circ.8$ C. has been observed in the polar regions (in Verkhoiansk, in Siberia[3]). The temperature of the Earth's surface in the polar regions certainly cannot fall to —89° C., owing to the air currents from the warmer regions. Hence, the mean temperature of the Earth's surface not heated by the Sun would be $\frac{-89-142}{2}$ $=115^\circ.5$ C., *i. e.*, $26^\circ.5$ higher than the temperature of celestial space ($-142°$ C.). Multiplying this difference by the ratio of the potential functions $\frac{U_1}{U}$, we obtain the minimum differences between the mean temperatures of the atmospheres of the planets and that of the celestial medium; adding to the differences $-142°$, we get the minimum of the mean temperatures (θ_2) of

[1] A. SPRUNG, *Lehrbuch der Meteorologie*, 1885, pp. 84–86.

[2] POUILLET, *loc. cit.* pp. 24–98.

[3] HANN, *Meteorol. Zeitschr.* **31**, 242, 1896; *Wildermann's Jahrbuch d. Naturwiss. für 1896–7*, **12**, 302.

the atmospheres of the planets and the Sun. The figures in column 5 of the table are the means of the two foregoing quantities.

In order to find the temperatures of the surfaces of the planets, not only must 142° be added to twice the numbers of column 4, but also the rise in temperature produced by the Sun's radiation. The latter raises the mean temperature of the Earth's surface from $-89°$ C. to $+15°$ C., *i. e.*, by 104°. We may, moreover, assume that only an inconsiderable quantity of heat passes from their nuclei into the atmospheres in case of the Earth and planets smaller than it, as the Moon, *Mercury*, *Venus*, and *Mars*. Then, using Stefan's law, according to which the radiation of a body varies directly as the fourth power of its absolute temperature, and supposing that the surfaces of the bodies are perfectly black, we may write

$$\frac{S}{4\pi R^2} T^4 = (t+\tau)^4 - 131^4 \qquad (11)$$

where $\frac{S}{4\pi R^2}$ represents the ratio of the apparent surface of the Sun seen from the body to the surface of the whole heavens, T the absolute temperature of the Sun's surface, t the absolute temperature of the surface of the body not heated by the Sun's radiation, τ the rise of temperature produced by that radiation, 131 the absolute temperature of the celestial space or medium. The first part of the equation is proportional to the radiation of the Sun, and the second to the difference between the radiation of the body and that of the surrounding celestial medium. Assuming the mean temperature $t+\tau$ of the surface of the Earth to be 288° (+ 15° C.), we shall find the "effective" temperature T of the Sun's surface (*i. e.*, its temperature if blackened) to be 5900° C.; substituting, moreover, in equation (11) the temperatures t_1 of the surfaces of the planets not heated by the Sun, placed in column 7 of Table II and calculated as I have just stated, we shall obtain the following values of τ: *Mercury* 320°, *Venus* 165°, the Earth and Moon 104°, *Mars* 96°. No doubt these numbers may differ very much from the true

values, because of the presence upon these planets of atmospheres having other densities and heights than that of the Earth.[1] Adding these numbers to the temperatures of the bodies which we have found above, we shall get the temperatures t_2 of the surfaces of the planets given in column 8 of the table.

In the case of the great planets, *Jupiter*, *Saturn*, *Uranus*, and *Neptune*, a term must be introduced expressing the quantity of heat which passes into their atmospheres from hot nuclei. As it is unknown, we cannot exactly calculate their heating due to the Sun's radiation, but on account of its smallness, we may assume it to be inversely proportional to the square root of the distance of those planets from the Sun[2]; then we shall find for

[1] How the presence of an atmosphere influences the temperature of the Earth's surface or that of the planets has not yet been explained. Supposing the atmosphere to be more transparent for the visible rays than for the invisible (infra-red), it is ordinarily assumed that its presence increases the mean temperature of the Earth. Thus, according to Pouillet, the mean temperature of the surface of the Earth without the atmosphere would be $-55°$ C. instead of $+15°$ C. (D. A. LATCHINOFF, *Meteorology and Climatology* (in Russian). St. Petersburg: p. 35), and according to Froelich $-39°$ C. (*id.* p. 36). But Müller, Abney (J. SCHEINER, *Strahlung und Temperatur der Sonne.* Leipzig, 1899, p. 9), and Langley's measurements (S. P. LANGLEY. "The Selective Absorption of Solar Energy," *Phil. Mag.* (5), **15**, 153–183, 1883; see *loc. cit.* 165), proved that red and infra-red rays are, on the contrary, more absorbed by the Earth's atmosphere. This may change our opinion that the atmosphere preserves from cooling. Nevertheless, Langley inferred that the mean temperature of the Earth's surface deprived of the atmosphere would be $-220°$ C. (W. TRABERT, "Das solare Klima," *Meteorol. Zeitschr.*, 1894, p. 425–427.) On the contrary, Trabert (*loc. cit.*) found this temperature to be $+35°.6$ C. (between $-273°$ C. in the polar regions in winter, and $+67°$ C. in the tropical regions in summer).

[2] This law was given by Christiansen (C. CHRISTIANSEN, "Nogle Bemaerkninger angaaende Planeternes Varmegrad." *Oversigt over det Kong. Danske Videnskabernes Selskabs Forhandlinger,* 1885. Kiobenhavn; see also GUILLAUME, *loc. cit.*). This was inferred from Stefan's law, assuming the celestial bodies to have no proper heat and the absolute temperature of celestial space to be zero; it may be deduced from the formula (11) by suppressing 134° and t. Using this law and Zöllner's numerical values of the albedo of the planets, Christiansen has given the following temperatures of the planets:

Name of Planet.	t	t'	Name of Planet.	t	t'
Mercury	210° C.	189° C.	*Jupiter*	−150° C.	−147° C.
Venus	57	65	*Saturn*	−180	−180
Earth	15	15	*Uranus*	−209	−207
Mars	−34	−40	*Neptune*	−221	−221

t is the surface temperature of the planet calculated from its albedo, and t' by Stefan's law.

Jupiter 46°, *Saturn* 34°, *Uranus* 24°, and *Neptune* 19°. All these values are placed in column 6 of the table.

Adding these figures to the surface temperatures of the bodies (without the effect of the Sun's radiation) calculated as above, we shall obtain the figures t_2 in column 8.

TABLE I.[1]

Name of Body.	$\frac{U_1}{U}$	Mean Temperature of the Atmosphere.			Surface Heating by the Sun's Radiation.	Mean Temperature of the Surface.		
		θ_1	θ_2	Mean θ		t_1	t_2	Mean t
1	2	3	4	5	6	7	8	9
Sun	2998.4	(+235000° C.	+79000° C.	+157000° C.	....	+470000° C.	+158000° C.	+314000° C.)
Mercury	0.16375	−129	−138	−133	320° C.	−116	+196	+40
Venus	0.8012	−79	−121	−100	165	−16	+65	+25
Earth	1	−635	−115.5	−89.5	104	+15	+15	+15
Moon	0.04750	−138	−141	−140	104	−134	−36	−85
Mars	0.19855	−126	−137	−131	96	−110	−36	−73
Jupiter	26.738	+1960	+565	+1260	46	+4060	+1320	+2690
Saturn	9.0814	+570	+99	+335	34	+1280	+374	+827
Uranus	3.0337	+96	−62	+17	24	+334	+42	+188
Neptune	4.1220	+180	−33	+74	19	+502	+95	+300

Examining this table, we see that the figures in column 8, headed t_2, are in the most evident accordance with our knowledge of the physical state of the planets, and *their real temperatures in all probability are the means of t_2 and t, θ_2 and θ.* But doubtless these figures cannot be exact, not only in the case of the planets and Sun, but also in the case of the Earth, and they must be regarded only as first approximations. We may suppose, however, that they give a fair idea of the facts. The figures given for the Sun are placed in parentheses, because our theory, assuming the bodies to consist of rigid nuclei surrounded

[1] In order to calculate the ratio $\frac{U_1}{U}$ the values of a and g are taken from the *Annuaire du Bureau des Longitudes pour l'an* 1898, p. 242. For the Sun, *Mercury*, *Venus*, the Moon, and *Mars*, the equatorial values are taken; for *Jupiter*, *Saturn*, *Uranus*, and *Neptune*, a was calculated from their volumes, and g at the parallel of 30° dividing the surface of the hemisphere into two equal parts (the last on account of collisions of free molecules of gases with the surface of bodies). We assumed the period of rotation of *Uranus* and *Saturn* $= 10^h$, which is the most probable value on account of the oblateness of *Uranus* and the velocities of revolutions of their satellites. For the Earth $a = 6378300\text{m}$, $g = 9.781 \frac{m}{\sec^2}$.

by gaseous atmospheres, cannot be strictly applied to the Sun, which is wholly gaseous.

This table shows that the temperature of the atmospheres and surfaces of the smaller bodies, as the Moon, *Mars*, the Earth, *Mercury*, and *Venus*, is low; on the contrary, that of the Sun and great planets, as *Jupiter*, *Saturn*, *Neptune*, is very high. This certainly corresponds with the facts. That the temperature of the Moon is low is the generally accepted opinion, and it has been confirmed by Langley's measurements of its radiant heat.[1] We have found its surface temperature to be between — 36° C. and — 134°, mean about — 85° C.

The same observations apply to *Mars*. Its surface temperature is between — 36° and — 110°, mean about — 73° C., and the great polar snows existing on its surface prove that its temperature is in reality low. According to Schiaparelli snow is observed not only at the poles but sometimes even near the equator.[2]

The surface temperatures of *Mercury* and *Venus* come out higher than for the Earth (about + 40° C. in the case of *Mercury* and + 25° C. for the surface of *Venus*) owing to their proximity to the Sun.

The temperature of the Sun is undoubtedly high. We do not know it exactly; our theory, as stated above, cannot be strictly applied to the Sun. I quote below the table of different determinations of the temperatures of the Sun given by Witz:[3]

Newton	1,669,300° C.	Spörer	27,000° C.
Pouillet	1,461	St. Claire Deville	2,500
Zöllner	102,000	Soret	5,801,846
Secchi	5,344,840	Vicaire	1,398
Ericsson	2,726,700	Violle	1,500
Fizeau	7,500	Rosetti	20,000[4]
Waterston	9,000,000		

[1] S. P. LANGLEY, "The Temperature of the Moon," *National Acad. of Sciences*, 1887. *Fortschritte der Physik*, **43** (3), 71, 1887.

[2] G. V. SCHIAPARELLI, *Himmel und Erde*, **1**, 1887; *Fortschritte der Physik*, **44**, 3te Abt., 68, 1887.

[3] AIMÉ WITZ, "Sur la température du soleil," *Mondes* (2), **51**, 381–385; *Fortschritte der Phys.*, **36**, 3te Abt., 78, 1880.

[4] The figures cited by J. SCHEINER (*Strahlung und Temperatur der Sonne*, Leipzig, 1899) differ considerably from those of Witz. Thus, according to Scheiner, Rosetti found the temperature of the Sun to be 9965°, Zöllner 13230° and 61350°, Violle 1550°.

We may add :

Langley	15,000,000° F.=8,333,000° C.[1]
Abney and Festing	12,700[2]
Wilson and Gray	8,700[3]
Pernter	30,000[4]
Ebert	40,000[5]
Guillaume and Christiansen	6,000[6]
Paschen	5,000[7]

J. Scheiner has shown that this discrepancy is caused by using different laws of radiation, viz., that of Newton, of Dulong and Petit, or of Stefan. Using but one, say Stefan's law, all the determinations based on the magnitude of the solar radiation give nearly the same numerical results, namely about 6000° C.[8] But this is the so-called "effective temperature" of the Sun, *i. e.*, that of a perfectly black body (lampblack) emitting the same quantity of heat as the Sun. But the radiant heat emitted by the photosphere is absorbed by the external atmosphere of the Sun; according to Laplace, only $\frac{1}{12}$ of the Sun's radiation is transmitted by its atmosphere; according to Pickering $\frac{1}{4.64}$, Frost 0.72, and Vogel 0.79 of red and 0.48 of violet.[9] On the other hand, the radiant surface of the Sun is not perfectly black; it is gaseous, and we do not know its emissive power. According to the observations of Rosetti,[10] for instance, the emissive power of the blue flame of a Bunsen's gas burner of infinitely great

[1] LANGLEY, *Proc. Amer. Acad.*, 1878, p. 106–113. *Fortschr. d. Phys.*, **36**, 3te Abt., p. 79, 1880.

[2] J. SCHEINER, *loc. cit.*, p. 36.

[3] W. E. WILSON and B. L. GRAY, *Phil. Trans.*, **185** (A), 1894, 361–369; *Beiblätter*, **19**, 428, 1895.

[4] J. PERNTER, "Bemerkungen zur Bestimmung der Sonnen-Temperatur." *Exner's Repertorium der Physik.*, **22**, 1–8, 1886.

[5] J. SCHEINER, *loc. cit.*, p. 59.

[6] C. E. GUILLAUME and CHRISTIANSEN, see above p. 243.

[7] J. SCHEINER; *loc. cit.*, p. 36. [8] J. SCHEINER, *loc. cit.*, p. 39. [9] *Ibid.*, p. 48.

[10] F. ROSETTI, "Sul potere assorbente, sul potere emissivo termico delle fiamme e sulla temperatura dell' arco voltaico," *Il Nuovo Cimento*, **8**, Series 3, 138–156, 185–203, 1880.

thickness is a third of that of a perfectly black body. Taking into account all these considerations, we find by means of Stefan's law that the temperature of the radiating strata of the Sun is about 12,000° C. But, doubtless, these strata are superficial, and the interior ones must have a higher temperature. J. Pernter[1] calculated that at the bottom of the chromosphere the temperature must be about 103300° C., if its height is 1500 geographical miles (11,000 km); Zöllner found that the temperature of the surface of the photosphere is 13,230° and at a depth of $\frac{1}{40}$ of the solar radius, 1,112,000° C.[2] Lane computed[3] that the temperature at the center of the Sun is such that the velocity of the molecules of hydrogen is no less than 331 miles a second, which corresponds to a temperature of about 22,000,000° C. According to Ritter[4] it is not less than 31,300,000° C. The great height of some solar protuberances confirms these calculations; they have been observed 560,000 kilometers high; J. Pernter[5] calculated that, in order to glow at that height, the temperature of hydrogen at the solar surface must be 5,868,000° C. The mean height of the protuberances according to Zöllner being 8,000 geographical miles (60,000 km) the temperature at the solar surface must be 1,100,000° C. The interior strata of the Sun must have a very high temperature for hydrogen to remain incandescent at such a distance from the Sun's surface, and it is possible that the mean temperatures of the solar atmosphere and surface which we found above (157,000° C. in the case of the atmosphere and 314,000° C. for the surface) correspond to strata of the Sun's atmosphere deeper than those from which we receive the radiation.

The temperature of *Jupiter* was found to be very high — between 1,320° C. and 4,060° C. All the observations confirm this conclusion. Thus Bond[6] found the emissive power of its

[1] J. PERNTER, *loc. cit.* [2] J. SCHEINER, *loc. cit.*, p. 54.

[3] J. H. LANE, "On the Theoretical Temperature of the Sun, etc," *Amer. Jour. of Science*, **50**, 57–74, 1870.

[4] A. RITTER, *loc. cit.*, **6**, 144, 1879. [5] J. PERNTER, *loc. cit.*

[6] BOND, "On the light of the Sun, Moon, *Jupiter* and *Venus*," *Monthly Notices*, **21**, 197–203. *Fortschr. d. Phys.*, **18**, 236, 1862.

surface to be twice that of the best white lead. It is therefore probable that *Jupiter* adds to the reflected sunlight light of its own. Bredikhin, on the basis of his many years' observations of the surface of *Jupiter*,[1] Lohse,[2] J. Scheiner,[3] and others have enunciated the opinion that *Jupiter* is a glowing body.

Taking the albedo (the fraction of the incident light reflected by the body) of *Mars* as unity, Müller[4] found the albedo of *Jupiter* to be 2.79 (according to Zöllner 2.34), of *Saturn* 3.28 (according to Zöllner 1.87), of *Uranus* 2.73 and of *Neptune* 2.36. Such albedo of *Jupiter*, the appearance of the clear (red) and dark spots on its surface and their continual variation,[5] the different velocity of rotation of the equatorial and other zones of its surface,[6] and particularly its small density (1.33, water as unity) all these facts afford irrefragable proofs of the high temperature of this planet. The dense and opaque atmosphere hides its glowing surface from our view, and we see therefore only the external surface of its clouds.[7] The objective existence of this atmosphere is

[1] BREDIKHIN, "Constitution de *Jupiter*," *A. N.*, IC, No. 2354. *Fortschr. d. Phys.*, **36**, 3 Abt., p. 35.

[2] O. LOHSE, "Beobachtungen und Untersuchungen über die physikalische Beschaffenheit des *Jupiters*, etc.," *Publ. d. Astrophys. Obser. zu Potsdam*, **1**, 93–132. *Fortschr. d. Phys.*, **36**, 3 Abt., 35.

[3] J. SCHEINER, "Ueber die physikalische Beschaffenheit der Planeten und Monde," *Naturw. Rundsch.*, **5**, 17–20, 42–44, 69–72. *Beiblätter zu Wied. Ann.*, **14**, 202, 1885.

[4] G. H. MÜLLER, "Helligkeitbestimmungen der grossen Planeten und Asteroiden," *Publ. d. Astrophys. Observ. zu Potsdam*, **8**, 369, 1893.

[5] Numerous observations by Denning, Barnard, Keeler, Holden and others; see *Fortschr. d. Phys.* für 1886, 1889, and other years.

[6] Observations by Denning, A. Bélopolsky, Serafimoff (*Fortschr. d. Phys.* for 1886, 1889, 1890, 1894). According to Bèlopolsky, the period of rotation of the equatorial zones of *Jupiter* is $9^h\ 51^m$, and $9^h\ 55^m$ for latitudes greater than 10°.

[7] The surface temperature of *Jupiter* is very much lower than that of the Sun; consequently the vapor of water may be condensed in opaque clouds at the height where its density is great. On the contrary, upon the Sun the temperature is so high that it can decrease to what is necessary for condensation of vapor only at a height where the density of the solar atmosphere is too inconsiderable to produce dense and opaque clouds.

proved by the bands and lines of absorption in its spectrum.[1] The interesting photograph obtained by Draper, September 27, 1879,[2] in which the blue and green parts are more brilliant for the equatorial zone than for the adjacent parts of the surface, appears to show that *Jupiter* emits its proper light. It is possible that the constant red spot noticed on its surface by several observers, as Gledhill, Lord Rosse and Copeland (1873), Russel and Bredikhin (1876),[3] is the summit of a high glowing mountain. G. W. Hough[4] considers *Jupiter* to be gaseous, and A. Ritter[5] inferred from his formulæ that in this case the temperature at its center would be 600,000° C.

On account of their great albedo and small density, we may assume that the other great planets, *Saturn*, *Uranus* and *Neptune*, also have high temperatures. These are, however, as I found above, considerably lower than that of *Jupiter*. Broad dark bands and lines are observed in the spectra of all these planets, as in the spectrum of *Jupiter*,[6] which proves that they are surrounded by slightly transparent atmospheres. The great albedo of *Saturn*, found by Müller, may be caused by the reflection from its clouds being more perfect than that of *Jupiter*, which is enveloped probably by the vapors of denser substances. According to Zöllner, the albedo of *Saturn* is, however, less than that of *Jupiter*.

Respecting the composition of the atmospheres of the planets, we can deduce some conclusions in the manner adopted by the present author in 1884 (*Journal of the Russian Physical and Chemical Society*, **16**, 524–538). The following is an extract:

[1] H. C. Vogel, *Untersuchungen über die Spectra der Planeten*, Leipzig, 1874, and "Neue Untersuch ü. d. Spectra d. Planeten." *Sitzungsber. d. Akad. d. Wissensch. zu Berlin*, pp. 1–25, 1895. Also J. Scheiner, *Die Spectralanalyse der Gestirne*, pp. 215–219, 1890.

[2] J. Scheiner, *Spectralanalyse der Gestirne*, p. 219.

[3] W. F. Denning, *Nature*, **58**, 331–332, 1898; *Beiblätter zu d. Annal. d. Phys. und Chem.*, **23**, 421, 1899.

[4] G. W. Hough, *Fortschr. d. Phys.*, **50** (3), 77, 1894.

[5] A. Ritter, *loc. cit.*, *Wied. Ann.*, **20**, 921, 1883.

[6] J. Scheiner, *Spectralanalyse*, pp. 215–224.

According to Maxwell's kinetic theory of gases their molecules are constantly flying with all possible velocities and in all conceivable directions, but there is in every gas a certain most probable velocity (*i. e.*, a velocity that differs but little from the velocities of the greater part of the molecules, depending only on the temperature and the nature of the gas.[1] Thus, the most probable velocity of the molecules of hydrogen at 0° C. is 1500 meters per second, vapor of water 502, nitrogen 401, air 395, oxygen 376. For carbon dioxide it is 320 and for the recently discovered helium, 1064 meters per second.

On the other hand it is shown in mechanics that, if the velocity of a material point subjected to the attraction of a body is greater than $\sqrt{2ag_0}$, where a is the radius of this body, and g_0 the acceleration of gravity at its surface, then this point travels in a parabola or hyperbola, and having once attained the surface of the body, streams away from it into infinity and never returns to it. Hence, if the most probable velocity of the molecules of any gas upon a certain celestial body have a value of about $\sqrt{2ag_0}$, this gas cannot be retained at the surface of the body.[2]

The following table gives an idea of this subject.

TABLE II.

(See the footnote on p. 244)

Name of body.	Mean distance from the Sun.	Mass m compared to that of the Earth.	Density. Compared to that of the Earth.	Density. Compared to that of water.	Radius a referred to that of the Earth as unity.	Acceleration g referred to that of the Earth as unity.	$\sqrt{2ag}$ meters per second.
Sun	.....	324439.	0.253	1.39	108.56	27.625	611700
Mercury	0.387	0.061	1.173	6.45	0.373	0.439	4520
Venus	0.723	0.787	0.807	4.44	0.999	0.802	9998
Earth	1.	1.	1.	5.50	1.	1.	11170
Moon	1.	0.013	0.615	3.38	0.273	0.174	2434
Mars	1.524	0.105	0.711	3.91	0.528	0.376	4997
Jupiter	5.203	309.816	0.242	1.33	10.856	2.462	57751
Saturn	9.539	91.919	0.128	0.70	8.958	1.014	33662
Uranus	19.183	13.518	0.195	1.07	4.106	0.739	19456
Neptune	30.055	16.469	0.300	1.65	3.798	1.0853	22679

[1] This velocity $= \sqrt{\frac{2}{3}}\, V$, where $V = \sqrt{\frac{3p}{\rho}}$ is the velocity of mean square, *i. e.*, the velocity the square of which is the mean of the squares of the velocities of all the individual molecules of a gas; p is the pressure and ρ the density of a gas. (See the footnote 1 on page 235.)

[2] The idea of the dependence of the presence of any gas in the atmosphere on

By comparison of the magnitudes of $\sqrt{2ag_0}$ with the most probable velocities of the molecules of several gases given above, we may conclude that the existence of vapor of water and, still more, of oxygen and nitrogen on the great planets is quite probable; on the contrary, their existence to any sensible extent upon the Moon and the small planets, for instance the asteroids, is hardly probable. Upon the Sun and great planets, for which $\sqrt{2ag}$ has a considerable magnitude, gases may exist of such small atomic weight that they cannot be present upon the Earth. It is possible that they are the elements giving certain lines in the Sun's spectrum, which cannot be identified with those of any terrestrial elements.

Knowing the temperatures of the atmospheres and surfaces of the planets, we may now deduce more precise conclusions on the composition of their atmospheres by proceeding as Dr. G. J. Stoney[1] has done.

As is known, the new element helium (atomic weight 2), was discovered by Ramsay in the gases imprisoned in the pores of the rare uranite minerals, such as clèveite, bröggerite, and others.[2] It is constantly supplied to the Earth's atmosphere by certain hot springs and volcanoes, and consequently if it could be retained by the Earth to any sensible extent, it would certainly accumulate in our atmosphere in the lapse of geological ages; but only a trace of helium is found in the atmosphere by H. Kayser,[3] Friedländer,[4] and Crookes.[5] Hence helium marks the

the ratio of the velocity of its molecules to the value of $\sqrt{2ag_0}$ has been treated by G. J. Stoney (ASTROPHYSICAL JOURNAL, **7**, 25–55, 1898), and the author, and has also been enunciated by G. HANSEMANN (*Die Atome und ihre Bewegungen*, Cöln, 1871, p. 97), TOLVER PRESTON (*Nature*, **19**, 3, 1878), H. BALL (*Science*, **21**, 99, 1893), C. H. BRYAN (*Science*, **22**, 311–313, 1893), and C. E. GUILLAUME (*Séances de la Société française de Phys.*, 1894, p. 258); but J. J. Waterston, in 1845, was the first to communicate this view to the Royal Society of London. His remarkable memoir, however, in which he deduced all the most important principles of the kinetic theory of gases, and gave a strict proof of its principal formula, was first printed by Lord Rayleigh in 1893 (J. J. WATERSTON, "On the Physics of Media that are Composed of Free and Perfectly Elastic Molecules in a State of Motion," *Phil. Trans.*, **183** A, 1893), and hence it remained unknown till then.

[1] G. JOHNSTONE STONEY, "Of Atmospheres upon Planets and Satellites," ASTROPHYSICAL JOURNAL, **7**, 25–55, 1898.

[2] RAMSAY, *Journ. Chem. Soc.*, **67**, 684–701, 1895; *Beiblätter*, **19**, 673, 1895.

[3] H. KAYSER, *Chem. News*, **72**, 89, 1895, and BOUCHARD, *Compt. Rend.*, **121**, 392–394, 1895; *Beiblätter*, **19**, 827, 1895.

[4] FRIEDLÄNDER, *Zeitschr. f. Physik. Chemie*, **19**, 657–667, 1896; *Beiblätter*, **20**, 775, 1896.

[5] CROOKES, *Chem. News*, **78**, 197–198, 1898; *Beiblätter*, **23**, 357, 1899.

boundary between the gases which can escape from the Earth and those which can not: all gases lighter than helium escape from the Earth, and all heavier are retained by it. Gases and vapors with atomic weights between 2 (helium) and 7 (lithium) are not found on the Earth, either because they do not exist, or because they were dissipated from the Earth when it was warmer than now. Helium and even hydrogen were retained in our atmosphere, mainly in its upper layers,[1] as being the constituents of the interplanetary medium, which may be considered as a continuation of the atmosphere of the Sun.

The most probable velocity of the molecules of helium is 1093 meters per second at 15°C., *i. e.*, at the mean temperature of the Earth's surface. $\sqrt{2ag}$ for the Earth is $11170 \frac{\text{km}}{\text{sec}}$.[2] Consequently, if the most probable velocity of the molecules of a gas or a vapor is $\sqrt{2ag}$ divided by 10.22 $\left(i.\ e.,\ \frac{11170}{1093}\right)$, corrected for centrifugal force, the gas or the vapor is not retained at the surface of the given celestial body. Thus the equation

$$W = \frac{\sqrt{2ag}}{10.22},$$

where W is the most probable velocity of the molecules of a gas, gives the minimum most probable velocity in a gas which escapes from the surface of the given celestial body. But we have

$$W = \sqrt{\frac{2p}{\rho} \cdot \frac{T}{273}}$$ [3]

or

$$W = \sqrt{\frac{2p}{\rho_1 \delta} \cdot \frac{T}{273}}$$

where ρ_1 is the density of hydrogen and δ, the density of the given gas referred to hydrogen as unity; $\sqrt{\frac{2p}{\rho_1}}$ is the most

[1] See p. 255 below.

[2] See Table II, p. 250. [3] See footnote 1 on p. 250.

probable velocity at 0°C., in hydrogen, $1505 \frac{m}{\text{sec.}}$. Hence we have the equation

$$1505 \sqrt{\frac{1}{\delta} \cdot \frac{T}{273}} = \frac{\sqrt{2ag}}{10.22}.$$

Substituting for $\sqrt{2ag}$ the values taken from Table II, and for T the absolute temperature at the surface of the planets, taken from Table I, we can determine the density δ (hydrogen=1) of gases which escape from the given celestial body as freely as helium does from the Earth.

If for T we put in the above equation 131°, assumed as the absolute temperature of celestial space and, at the same time, as the temperature of the upper strata of the atmospheres of the planets and the Sun, we obtain the maximum density of gases which escape from the atmospheres of the celestial bodies.

The first column of Table III contains the names of the celestial bodies; the second, $\frac{U_1}{U}$, the ratio of the potential functions of gravitation, corrected for rotation at the surface of the body to that at the surface of the Earth; the third, the mean temperatures of the surfaces of the bodies taken from Table I; the fourth, the densities of gases referred to that of hydrogen as unity, which escape from the surface of the bodies as freely as helium does from the Earth's surface; the fifth column, the density of gases not retained in the upper strata of the atmospheres; the sixth column gives Dr. Stoney's numbers for the densities of gases escaping from the upper strata of the atmospheres of the bodies as freely as helium escapes from the Earth's atmosphere. We see that they have greater values than the figures in the sixth column, for Dr. Stoney[1] has taken for the temperature of the upper limits of the atmospheres of the planets and the Earth −66°C. The last assumption cannot be admitted on account of the temperature −69.8°C. being observed at the surface of the Earth, and −75°C. at 11,000 meters.[2]

[1] *Loc. cit.*, p. 34 and following.

[2] See p. 241 and footnote 3 on p. 239.

TABLE III.

Name of Body.	$\frac{U_1}{U}$	Temperature at the Surface.	Maximum Density of the Gas[1] (H=1). Not Retained at the Surface.	Not Retained at the Upper Strata of the Atmosphere.	G. J. Stoney's Results.
Sun	2998.4	+314000° C.	0.721	0.000304	.....
Mercury	0.16375	+40	13.0	5.6	10–11
Venus	0.8012	+25	2.6	1.25	.....
Earth	1	+15	2	0.9	2
Moon	0.04750	−85	28	19	39
Mars	0.19855	−73	6.9	4.6	9.57
Jupiter	26.738	+2690	0.76	0.05	0.099
Saturn	9.0814	+827	0.82	0.17	0.37
Uranus	3.0337	+188	1.0	0.44	0.74
Neptune	4.1220	+300	0.94	0.30	0.68

Multiplying the numbers of the fourth and fifth columns by $\sqrt{\frac{9}{2}}$, we shall get the densities of gases which are retained at the surface and in the upper strata of the atmospheres as firmly as is water vapor in the Earth's atmosphere.

From the above table we see that the atmosphere of the Sun may contain not only hydrogen, but also gases many times lighter than hydrogen, if any such exist.

Owing to the lower temperature of the upper strata of the atmospheres, they can contain gases and vapors which cannot exist in the lower layers. Thus, in the higher strata of the Earth's atmosphere, helium and, perhaps, even hydrogen may be retained. In fact, the helium line λ 5015.9[2] may perhaps correspond with the line λ 5000.5, observed by Vogel, Capron,[3] and others in the spectrum of the aurora borealis, and by Vogel and Schuster[4] in the spectrum of lightning ($\lambda = 5002\,\mu\mu$). It is not possible to determine what element produces these lines of the aurora borealis and lightning. Exact measurement under

[1] Referred to hydrogen as unity; it is equal to atomic weight for elementary gases.

[2] W. Crookes, *Zeitschr. anorg. Chem.*, **11**, 6–13, 1896; *Beiblätter*, **20**, 275, 1896.

[3] J. Scheiner, *Die Spectralanalyse der Gestirne*, p. 335, Leipzig, 1890.

[4] H. Kayser, *Lehrbuch der Spectralanalyse*, p. 115.

the given conditions is attended with great difficulty, as appears from the fact that the differences in the wave-length of the characteristic yellow-green line of the aurora borealis (λ 5570.9)[1] measured by various observers reaches about 1.6 meters.[2] In like manner, many lines of the aurora borealis given by Professor Vogel[3] are near the lines of rarefied hydrogen as given by Hasselberg.[4] On June 18, 1897, at the Arequipa Observatory, the spectrum of a meteor was photographed, containing six lines at wave-lengths 3954, 4121, 4195, 4344, 4636, 4857, and the corresponding intensities of about 40, 100.2, 13, 10, 10. Four of these lines, viz., the first, the second, the fourth, and the sixth are not far from the hydrogen lines $H\epsilon$ (λ 3970.), $H\delta$ (λ 4101), $H\gamma$ (λ 4341), and $H\beta$ (λ 4862).[5] In fact, helium is present even at the surface of the Earth, as is shown by the experiments of Kayser, Friedländer and Crookes,[6] and a trace (0.02 per cent.) of free hydrogen has now been discovered by A. Gautier.[7] These gases are carried from the upper to the lower strata of our atmosphere by currents of air. It is possible, also, that the green line of the spectrum of the aurora borealis is due to coronium, which is, probably, an element lighter than hydrogen, being observed only in the upper regions of the Sun's atmosphere, or to other unknown elements lighter than hydrogen.

In the atmosphere of the Moon, not only such gases as oxygen, nitrogen, and vapor of water cannot be retained, but even carbon dioxide; the denser gases, owing to the low temperature prevailing on the Moon ($-85°$ C.), can be only in the fluid or solid state, and therefore, if the Moon has an atmosphere, it must be of insensible density. This opinion has been confirmed

[1] Perhaps this line belongs to some unknown element lighter than helium.

[2] J. SCHEINER, *loc. cit.*, p. 336. [3] *Id.*, p. 325.

[4] H. KAYSER, *Lehrbuch der Spectralanalyse*, p. 279.

[5] E. C. PICKERING, "Spectrum of a Meteor," *A. N.*, **145**, 3461, 1898.

[6] See p. 251.

[7] A. GAUTIER, *Bulletin de la Société chimique de Paris*, Dec. 5, 1900, p. 884; *Beiblätter*, **25**, 2, 1901.

by the most careful observations of the occultations of stars by the Moon. According to Pickering,[1] the density of the Moon's atmosphere is not greater than $\frac{1}{4000}$ of that of the Earth's atmosphere. Spectroscopic observations lead to the same conclusion: by reflection of the sunlight from the surface of the Moon the Fraunhofer lines are not strengthened and no new lines or bands appear in the spectrum.[2]

Upon *Mercury*, at least on the side exposed to the sunlight, not only vapor of water but even oxygen and nitrogen cannot, probably, remain in the inferior strata of its atmosphere; these gases can accumulate only on the dark side and in the upper strata. Spectroscopic observations yield contradictory results, being very difficult owing to the small distance of the planet from the Sun. While some observers found the telluric lines in the spectrum of *Mercury* to be stronger, indicating the presence of an atmosphere like that of the Earth,[3] Professor Vogel did not observe this.[4]

The composition of the atmospheres of *Venus* and *Mars* may be the same as that of the Earth; but the force of gravity on these planets being less, their atmospheres must be less dense than that of the Earth, particularly on *Mars*. It is probable that water vapor exists even in the atmosphere of Mars, but in consequence of its low temperature in less quantity than in our atmosphere. This is confirmed by the spectroscopic observations of Huggins and Maunder, and particularly by the careful observations made during many years by Professor Vogel,[5] which show that in the spectra of these planets some of the

[1] W. H. PICKERING, *Astronomy and Astro-Physics*, **11**, 778–781, 1892; *Fortschr. d. Phys.* **48** (3), 60, 1893.

[2] J. SCHEINER, "Ueber die physikalische Beschaffenheit der Planeten und Monde," *Naturw. Rundschau.*, **5**, 17–20, 41–44, 69–72, 1883. *Fortschr. d. Phys.*, **42**, (3), 100–106, 1886.

[3] *Ibid.*

[4] H. C. VOGEL, *Neue Untersuchungen über die Spectra der Planeten*. Leipzig, 1874.

[5] *Ibid.*, and J. SCHEINER, the above footnote. According to Stoney there is no water.

telluric lines are stronger. W. W. Campbell[1] did not observe such a selective absorption in the case of *Mars*, and this shows that the density of its atmosphere and especially of the vapor of water cannot be great. In consequence of the low temperature on *Mars* (between $-110°$ and $-36°$, mean $-73°$ C.) the water upon its surface must be mainly in the solid state, carbon dioxide in the gaseous and solid state[2] and only oxygen and nitrogen as gases. Its distance from the Sun being 1.5 that of the Earth, the heat received by *Mars* from the Sun's radiation is only half of that received by the Earth, and the polar ice and snows which we see melting upon its surface when exposed to solar radiation are probably composed of carbon dioxide or some other body freezing at a temperature near $-73°$ C., for otherwise this ice could not melt so quickly as it is observed to do.[3] Being a denser constituent of the atmosphere, vaporized carbon dioxide cannot rise or form clouds like aqueous vapor on the Earth. It passes along the surface of *Mars* to its equator at the bottom of the atmosphere by canals and valleys, raising the lighter constituents. Water vapor may then form clouds, but composed of spicules of ice like our cirrus, which probably cause the gemmination of the canals, like the muslin in the experiments of H. Meunier.[4] Reflecting the Sun's rays, these clouds possibly produce the projections observed by Douglass in 1900 and Gledhill in 1899. Ordinary clouds and rain cannot exist on *Mars*; its

[1] W. W. Campbell, "The Spectrum of the Planet Mars," *Astronomy and Astro-Physics*, **13**, 752–760, 1894; *Fortschr. d. Phys.*, **50**, 58, 1894; **51** (3), 60, 1895.

[2] Carbon dioxide at the ordinary atmospheric pressure boils at $-79°$ C.; at 5 mm pressure it boils at $-125°$ C., and freezes at the same time; when the pressure is lower than 760 mm (and even 5 atmospheres) as upon *Mars*, carbon dioxide passes directly from the solid to the gaseous state. (*P. Villard* et *Jarry*. "Neige carbonique." *Comptes Rendus*, **120**, 1413–1416, 1895; *Séances de la Société française de physique*, 1895, 177–185).

[3] S. Meunier, "Cause possible de la gemmination des canaux de *Mars*." *Comptes Rendus*, **115**, 678–680, 901–902, 1892; *Géologie comparée*. Paris, 1896. Meunier took a polished metal ball on which black stripes were traced, representing the canals of *Mars*, and enveloped it in muslin; when a beam of light was incident on it, these black stripes were seen accompanied by others, parallel to them, which were produced by their shadows cast on the muslin envelope.

[4] *Ibid.*

polar white spots are perhaps hoar frost, like that which settles on our trees and earth, directly condensed from the atmosphere.

As free oxygen and carbon dioxide may exist in the atmosphere of *Mars*, vegetable and animal life is quite possible. If the temperature which prevails upon *Mars* is nearer to —36° C. than to —73° C., the existence of living beings like ourselves is possible. In fact, the ice of some Greenland and Alpine glaciers is covered by red algae (*Sphaerella nivalis*); we find there, also, different species of rotatoria, variegated spiders, and other animals on the snow fields illuminated by the Sun; at the edge of glacier-snows in the Tyrol we see violet bells of *Soldanella pusilla*, the stalks of which make their way through the snow by producing heat which melts it round about them[1]. Finally, the Siberian town of Verkhoiansk, near Yakutsk, exists though the temperature there falls to —69°.8 C., and the mean temperature of January to —51°.2, and the mean pressure of the vapor of water is less than 0.05 mm.[2] It is possible, therefore, that living beings have become adapted to the conditions now prevailing upon *Mars* after a lapse of many ages, and live at an even lower temperature than upon the Earth, developing the necessary heat themselves.

If the temperature on *Mars* is near to —73° C., or lower, the part played by water may there be played by another substance remaining liquid at —73°.C. Water in organisms is mainly a liquid medium or solvent, and many other liquids may be the same. We have no reason to believe that life is possible only under the same conditions and with the same chemical composition of organisms as upon the Earth, although, indeed, we cannot affirm that they actually exist on *Mars*.

The atmospheres of the planets *Jupiter*, *Saturn*, *Uranus*, and *Neptune* may contain gases lighter than the Earth can retain, and even lighter than hydrogen, if any such exist. In consequence of more intense gravitation, the density and the height of their atmospheres must be greater than on the Earth. The

[1] A. KERNER V. MARILAUN, *Pflanzenleben*.

[2] W. OVERMANN'S *Jahrb. d. Naturwissenschaften*, **13**, 278, 1897–8.

spectroscopic observations of Secchi, Vogel, Huggins, Janssen, Keeler, and Lockyer confirm these deductions, because the spectra of these planets, besides the ordinary solar and telluric lines, contain some other dark lines and bands, so that the composition of their atmospheres undoubtedly differs from that of the Earth.[1]

Table I may give us a complete idea of the climatic conditions upon the planets. So we see, for instance, that the temperature at the surface of *Mercury* is high owing to strong heating by the Sun, although its own heat is small. Owing to this heating, the difference between the temperatures of the illuminated and dark sides must be very great, particularly since the same side of this planet is always turned to the Sun. The same is true for *Venus*, though in less degree; as its temperature is almost like that of the Earth ($+25°$ C.) it is possible that life may exist on its surface. On the contrary, for the great planets *Jupiter* and, in particular, *Saturn*, *Uranus* and *Neptune*, owing to the small heating by the Sun, the temperature is almost uniform over the whole surface and without sensible diurnal and annual variations.

In conclusion, I wish to call attention to a single circumstance. If in formula (7) ρ, the density of a gas at the Earth's surface, is made equal to unity, we obtain

$$\alpha k_0 \log. \rho_1 = \frac{a_1 g_1}{T_1} - \frac{ag}{T} \ ;$$

differentiating with respect to ρ and T, we have

$$\frac{d\rho_1}{\rho_1} = \frac{1}{\alpha k_0} \cdot \frac{a_1 g_1}{T_1} \cdot \frac{dT_1}{T_1} \ .$$

Since $\frac{a_1 g_1}{\alpha k_0 T_1} = \frac{ag}{\alpha k_0 T}$ is about 3000,[2] we see that a small variation of the temperature of a celestial body produces a large variation in the density of its atmosphere, owing to the passage of gases from the interplanetary medium into the atmosphere, or conversely. This alters the mass of the

[1] J. SCHEINER, *Die Spectralanalyse der Gestirne*, p. 210.

[2] See p. 236.

heavenly body, which may have some influence on its motion. Likewise, the asymmetrical heating, produced by the Sun's radiation, of the surface of such planets as *Mercury* and *Venus*, which always turn the same face to the Sun, must increase the asymmetry of the body by the condensation of matter on the side turned away from the Sun.

The above results certainly cannot pretend to be exact, the distribution of temperature through interplanetary space being completely unknown; but they show that even such apparently accidental circumstances as the temperature and composition of the atmospheres of celestial bodies, are in fact not accidental, but necessary consequences of the general laws of universal gravitation, radiant heat, and the nature of gases. In reality, the atmospheres of all the planets and of the Sun are in material connection, and phenomena occurring upon one of them, at least on the Sun, affect the rest, although after a considerable time. As science advances we may expect more precise knowledge regarding the atmospheres of celestial objects. It is perhaps not too much to hope that observational means of verifying the results derived from theory may ultimately be available. In any event, there is every season to anticipate that many questions of astrophysics will be cleared up through advances in the spectroscopic and photometric study of radiation.

ST. PETERSBURG,
September, 1901.

MINOR CONTRIBUTIONS AND NOTES

OBSERVATIONS OF THE SPECTROSCOPIC BINARY *CAPELLA*.[1]

THE first magnitude star *Capella* was discovered to be a spectroscopic double star early in August, 1899, from an examination of the plates of its spectrum secured with the Mills spectrograph in 1896. Announcement of the fact was made to the Astronomical and Astrophysical Society of America at the meeting of September 7, 1899, and in the ASTROPHYSICAL JOURNAL for October, 1899.

Independent discovery of its binary character was made by Mr. H. F. Newall, of Cambridge, England, in November, 1899, and announced in the *Monthly Notices of the Royal Astronomical Society* for November.

The spectra of the two components are distinguishable on most of the plates — the exceptions being those taken when the radial velocities of the two were nearly equal, producing a superposition of the two sets of lines. The spectrum of the principal star is of the solar type, whereas that of the secondary is intermediate between the solar and Sirian types.

The velocities of the principal component, as observed with the Mills spectrograph, are given in the following table:

No.	Date. Greenwich M. T.			Velocity. Kilometers.	No.	Date. Greenwich M. T.			Velocity. Kilometers.
1	1896	Sept.	1.036	+36.4 C	17	1899	Nov.	6.026	+54.8 C
2			17.005	53.8 C	18			27.952	43.2 W
3		Oct.	4.003	50.3 C	19			27.966	44.0 W
4			6.029	46.9 C	20		Dec.	3.730	35.2 C
5		Nov.	12.865	4.2 C	21			18.648	12.6 W
6	1899	Aug.	12.999	48.3 C	22			24.882	7.7 W
7			27.052	26.1 C	23	1900	Jan.	10.649	7.7 C
8		Sept.	12.950	5.7 W	24			21.740	21.7 W
9			20.006	5.1 W	25		Feb.	11.724	50.0 W
10			20.919	3.5 W	26			26.726	55.2 W
11			20.933	5.4 W	27			26.740	54.8 C
12			25.909	6.6 C	28		Aug.	2.012	3.6 C
13		Oct.	3.988	14.8 C	29		Sept.	19.944	55.5 C
14			16.012	32.9 C	30			24.950	53.9 C
15			16.929	32.0 C	31			27.005	53.7 C
16			31.892	52.0 C					

[1] *Lick Observatory, University of California, Bulletin* No. 6.

[Measures of the plates by Campbell and Wright are indicated by C and W respectively.]

The presence of the second component's spectrum interferes considerably with the measures of that of the first component, and the probable error of a single observation, ± 0.50 kilometer, deduced by Dr. Reese, is as small as could be expected. Measures of the speed of the second component are somewhat uncertain, but an estimated range of from -3 to $+63$ kilometers will not be far from the truth. The velocity of the principal component in the line of sight ranges from $+4.2$ to $+55.7$ kilometers. The masses of the two components are therefore as 1.26 to 1.

The solar-type component is estimated to be half a magnitude brighter, photographically, than the bluer component. In the visual portion of the spectrum the solar component is probably at least a whole magnitude the brighter of the two.

Inasmuch as the spectroscope takes account of the component of speed in the line of sight, and is powerless to measure the component at right angles to the line of sight, the spectroscopic orbit is determinate in form but indeterminate in size. The inclination of the orbit-plane remains unknown. The minimum orbit capable of satisfying the observed velocities corresponds to the case of the orbit-plane passing through the observer. In this case the maximum distance between the two components would be about 85,000,000 kilometers; and, if Elkin's value of the parallax of *Capella*, $0''.08$, is correct, the angular separation of the components, as viewed from the solar system, would approximate $0''.045$ when passing through the nodes. Such an orbit would give rise to eclipses every fifty-two days. No variations in the brightness of *Capella* having been observed, it is safe to assume that the orbit-plane makes an appreciable angle with the line of sight.

In the case of a great number of orbit-planes distributed fortuitously, the most probable value of the angle between the normal to the orbit-plane and the line of sight would be $60°$. The corresponding angular separation of the components at the nodal points would be about $0''.052$. In case this angle should be $30°$, the corresponding separation would be $0''.09$.

The question as to whether *Capella* could be observed as an ordinary double star early arose. It was most carefully examined with the 36-inch refractor on several occasions in 1900 and 1901 by Messrs. Hussey and Aitken, and on one occasion by Mr. Perrine; but neither

duplicity nor elongation could be detected. Their observations were made under the most favorable conditions, and we may conclude that the angular separation of the components is less than 0."06.

A discussion of the probable masses of the components with reference to the mass of our Sun seems to be futile, on account of the impossibility of harmonizing the best available data for the parallax and brightness of *Capella*, the brightness of our Sun, and the angular separation of the components. W. W. CAMPBELL.

JULY 25, 1901.

A DETERMINATION OF THE ORBIT OF *CAPELLA*.

The announcement that *Capella* is a spectroscopic binary was made by Professor Campbell in the ASTROPHYSICAL JOURNAL for October, 1899, and afterwards by Mr. H. F. Newall in the *Monthly Notices of the Royal Astronomical Society* for November, 1899. It will be recalled that Vogel and Scheiner had photographed the spectrum from October 6, 1888, to September 15, 1889; but failed to detect its binary character, their spectroscope being apparently incapable of resolving the composite spectrum. Consequently their measurements give the mean displacements of two sets of lines, and their reductions an approximation to the velocity of the center of mass of the system.

The following computation is based on thirty-one observations of the velocity in the line of sight of the solar-type component, made with the Mills spectrograph at intervals between September 1, 1896, and September 27, 1900. The plates were exposed and the measurements and reductions carried out by Director Campbell and Mr. W. H. Wright. The method of computing the orbit is exactly that given by Lehmann-Filhés (*Astronomische Nachrichten*, No. 3242), except that in the equations of condition the correction to the velocity of the center of mass of the system is introduced as a sixth unknown, with coefficient unity. The period 104.1 days was assumed as best agreeing with the observations, and the observed velocities were plotted as functions of the time-interval after the next preceding minimum, assuming September 18.9, 1899, as a time of minimum. A smooth curve was drawn through the points so obtained, and by means of a planimeter the line representing the velocity of the center of mass of the system was drawn so as to enclose equal areas with the portions of the curve above it and below it. The other requisite quantities were then obtained in the way shown in the article already cited. The following is the list of provisional elements thus found:

$U = 104.1$ days, period.
$\left.\begin{aligned}\mu &= 3^\circ\!.4582 \\ &= 0.060357 \text{ radians}\end{aligned}\right\}$ average daily motion.
$\omega = 123^\circ\!.041$, position of periastron.
$T = -15.8$ days, time of periastron passage from September 18.9, 1899.
$e = 0.02$, eccentricity of orbit.
$a \sin i = 36{,}997{,}900$ kilometers.

$$K = 25.85 = \frac{\mu}{\sqrt{1-e^2}}\,\frac{a \sin i}{86400}\,.$$

$V = +30.0$ kilometers per second, velocity of center of mass of system.

Before computing an ephemeris with these elements, certain of the observations were combined in pairs so as to form in all twenty-seven normal places. These were weighted on the assumption that all the thirty-one original observations were equally reliable; that is, a normal place formed by combining two observations was given weight 2, and all uncombined observations weight 1.

No.	Date. Gr. M. T.			Observed Velocity.	O−C Prelim. Orbit.	O−C Final Orbit.	Comparison ▭ of Residuals.
				Kilometers.	Kilometers.	Kilometers.	Kilometers.
1....	1896	September	1.036	+36.4	−2.13	−0.83	+0.11
2....			17.005	53.8	−0.63	−0.38	+0.04
3....		October.... ...	4.003	50.3	+1.11	+0.08	−0.03
4....			6.029	46.9	−0.05	−1.20	−0.05
5....		November......	12.865	4.2	+0.30	−0.02	−0.04
6....	1899	August	12.999	48.3	+1.24	+1.09	+0.01
7....			27.052	26.1	−0.16	−0.43	0.00
8....		September	12.950	5.7	+0.02	−0.39	0.00
9....			20.006	5.1	+1.18	+0.84	0.00
10....			20.919	3.5	+0.43	−0.86	+0.01
11....			20.933	5.45		+1.08	
12....			25.909	6.6	+0.47	+0.24	−0.02
13....		October........	3.988	14.8	+0.98	+0.92	+0.01
14....			16.912	32.9	+0.19	+0.65	+0.01
15....			16.929	32.0		−0.28	
16....			31.892	52.0	+0.99	+0.84	−0.01
17....		November......	6.026	54.8	+0.41	+0.24	0.00
18....			27.952	43.2	+0.14	−0.34	+0.01
19....			27.966	44.0		+0.48	
20....		December......	3.720	35.2	+0.22	+0.14	+0.01
21....			18.646	12.6	+0.13	−0.17	−0.02
22....			24.882	7.7	+1.26	+0.91	0.00
23....	1900	January........	10.649	7.7	−0.42	−0.66	0.00
24....			21.740	21.7	+0.30	+0.18	0.00
25....		February........	11.724	50.0	+0.12	−0.08	0.00
26....			26.726	55.2	−0.03	+0.04	+0.04
27....			26.740	54.8		−0.36	
28....		August.........	2.012	3.6	−1.34	−1.70	−0.02
29....		September	19.944	55.5	−0.06	−0.24	−0.01
30....			24.950	53.9	−0.32	−0.34	+0.02
31....			27.005	53.7	+0.69	+0.72	−0.03
				[*pvv*]	16.820	13.988	

The accompanying table gives the data of the observations. The date is given in the second column and the observed radial velocity relative to the Sun in the third. The observations combined to form normal places are the tenth and eleventh, the fourteenth and fifteenth, the eighteenth and nineteenth, and the twenty-sixth and twenty-seventh. Column 4 gives the residuals from the velocities computed with the above provisional elements. It will be seen that the greatest residual in absolute amount is 2.13 kilometers, and the sum [*pvv*], 16.820.

The equations of condition formed according to the method of Lehmann-Filhés are given below, each equation being followed by its weight:

$+0.330\,\delta K$	$-3.16\,\delta e$	$+23.87\,\delta\omega$	$-25642\,\delta\mu$	$-1.412\,\delta T$	$+\delta V$	$+2.13=0$	1
$+0.945$	-23.76	$+7.17$	-7969	-0.445		$+0.63=0$	1
$+0.742$	$+19.64$	-17.44	$+18207$	$+1.033$		$-1.11=0$	1
$+0.656$	$+23.22$	-19.71	$+20692$	$+1.176$		$+0.05=0$	1
-1.010	-11.75	$+0.91$	-1410	-0.083		$-0.30=0$	1
$+0.660$	$+23.09$	-19.60	$+409$	$+1.170$		$-1.24=0$	1
-0.145	$+8.06$	-26.05	$+187$	$+1.603$		$+1.16=0$	1
-0.941	-25.20	-9.94	-98	$+0.594$		$-0.02=0$	1
-1.009	-11.37	$+1.12$	$+27$	-0.096		$-1.18=0$	1
-1.004	-8.64	$+2.60$	$+55$	-1.186		$-0.43=0$	2
-0.923	$+6.86$	$+10.15$	$+243$	-0.643		$-0.47=0$	1
-0.626	$+24.34$	$+19.95$	$+622$	-1.215		$-0.98=0$	1
$+0.088$	$+9.37$	$+25.29$	$+1098$	-1.512		$-0.19=0$	2
$+0.813$	-25.17	$+14.22$	$+831$	-0.853		$-0.99=0$	1
$+0.944$	-23.86	$+7.29$	$+479$	-0.452		$-0.41=0$	1
$+0.521$	$+25.83$	-22.33	-1913	$+1.345$		$-0.14=0$	2
$+0.192$	$+21.84$	-25.75	-2387	$+1.572$		$-0.22=0$	1
-0.678	-20.02	-19.70	-2136	$+1.210$		$-0.13=0$	1
-0.912	-25.84	-11.67	-1342	$+0.702$		$-1.26=0$	1
-0.847	$+14.31$	$+13.76$	$+1840$	-0.857		$+0.42=0$	1
-0.333	$+24.18$	$+24.04$	$+3360$	-1.442		$-0.30=0$	1
$+0.769$	-24.12	$+15.75$	$+2520$	-0.941		$-0.12=0$	1
$+0.968$	-4.33	-5.69	-916	$+0.313$		$+0.03=0$	2
-0.970	$+0.04$	$+6.92$	$+2476$	-0.449		$+1.34=0$	1
$+0.989$	-12.89	-1.14	-265	$+0.042$		$+0.06=0$	1
$+0.937$	$+1.86$	-8.69	-3162	$+0.493$		$+0.32=0$	1
$+0.890$	$+8.11$	-11.64	-4337	$+0.673$		$-0.69=0$	1

These equations were rendered more nearly homogeneous by dividing the coefficients of δe by 10, those of $\delta\omega$ by 10, and those of $\delta\mu$ by 1,000. The normal equations were then found to be as follows:

$+18.944\,\delta K$	$+3.918\,\delta e'$	$-6.638\,\delta\omega'$	$+1.642\,\delta\mu'$	$+4.024\,\delta T$	$+1.619\,\delta V$	$+1.068=0$
	$+96.913$	-16.972	$+108.588$	$+10.295$	$+1.287$	$-2.194=0$
		$+80.515$	-86.551	-48.520	-2.644	$+7.921=0$
			$+1563.748$	$+51.160$	-0.207	$-73.384=0$
				$+29.252$	$+1.300$	$-4.653=0$
					$+31.000$	$-5.77=0$

The solution gave the following corrections to the provisional elements:

$$\delta\mu = +0.0000453 \text{ radians.}$$
$$\delta\omega = -0.0995 \text{ radians} = -5^\circ.6990$$
$$\delta T = -1.553 \text{ days.}$$
$$\delta e = -0.00361.$$
$$\delta K = -0.086.$$
$$\delta V = +0.1727 \text{ kilometers.}$$

The substitution of these values in the equations of condition gives 1.72 as the greatest residual and 11.411 as the sum $[pvv]$. In the final ephemeris, however, the combinations of observations were discarded and the velocity computed for each of the thirty-one observations. The corresponding residuals are shown in column 5, the greatest being 1.70. It was found, as might be expected, that the sum $[pvv]$ obtained in this way is considerably greater than that obtained from the equations of condition. This is because in each of the four combinations the two observations fall on opposite sides of the curve, so that twice the square of the mean residual is much less than the sum of the squares of the two residuals. Accordingly, the greater value of the sum, 13.988, was used in computing the probable errors.

The sixth column of the table shows the difference between the residuals given by the final ephemeris and those given by the several equations of condition. It is inserted merely to show how far the neglect of second powers in the equations of condition is justified. In those cases where two observations are combined, the velocity for the mean date was not computed directly, but was assumed to be the mean of the two velocities, an assumption justified by the close proximity of the two dates in each of these cases.

The probable error of a single observation is ± 0.50 kilometer per second. The final values of the elements, with their probable errors, are given below:

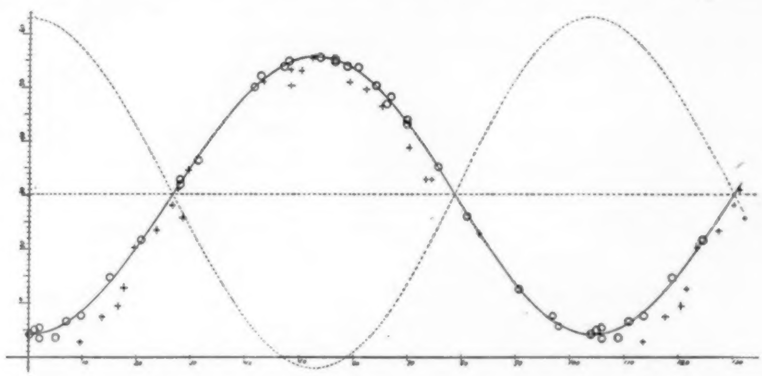
$$\omega = 117^\circ.3 \pm 18^\circ.3.$$
$$\mu = 0.060403 \pm 0.000014 \text{ radians.}$$
$$= 3^\circ.46082 \pm 0^\circ.00081.$$

$T = -17.4 \pm 5.3$ days, the actual date being September 1.5, 1899.

$$e = +0.0164 \pm 0.0055.$$
$$K = 25.76 \pm 0.12.$$
$$U = 104.022 \text{ days} \pm 0.024 \text{ days.}$$
$$a \sin i = 36{,}847{,}900 \text{ kilometers.}$$
$$V = +30.17 + 0.104 \text{ kilometers per second.}$$

The great uncertainty in the values of ω and T is due to the fact that the orbit is so nearly circular. The probable errors of the other quantities are small in view of the difficulty of measuring the spectrum of this star.

The computed velocity-curve is shown in the diagram, abscissæ representing times (taking September 18.9, 1899, as the epoch), and ordinates the corresponding velocities in the line of sight. The points marked by circles represent the thirty-one observations from which the elements were computed. Mr. Newall's observations are also plotted,



and are marked by crosses. It will be noted that of his twenty-three observations, two fall on the curve, two very slightly above it, and the remaining nineteen below it, generally several kilometers below. His observations would be fairly well represented by the elements here given if the quantity V were made somewhat smaller.

The dotted line parallel to the time-axis represents V, the velocity of the center of mass.

The dotted curve represents roughly the radial velocity of the lesser component of the system. Its orbit would differ from that of the principal component only in the value of a (or, what is the same thing, in that of K), and in ω, which would differ 180° from the ω of the principal component.

At any moment the line-of-sight velocities of the two components relative to their center of mass would be in a constant ratio; that is,

$$\frac{V_1 - V}{V_2 - V} = \frac{K_1}{K_2} = \frac{-a_1}{a_2} .$$

No very satisfactory determinations of the lesser component's velocities are at hand, but a few measurements have been made of sufficient accuracy to assign to the above ratio the approximate value of — 1.26, and the dotted curve was plotted on this basis.

By carrying back the period of 104.022 days to 1888 and 1889, the observations of Vogel and Scheiner can be compared with the orbit. It is found that their plate numbered 19 was taken at a time when the relative velocity of the two components was about zero. This plate they marked "excellent." Four other plates, numbered respectively 14, 15, 18, and 67, and marked "very good," "good," etc., were taken at times when the velocity of the solar component relative to the center of mass was 9 kilometers or less. One plate, numbered 95, is marked as rather poor except for a good $H\gamma$ line, although the velocity of the solar component relative to the center of mass was only 6 kilometers. With this exception, all plates marked "verwaschen," "uncertain," etc., were taken when the relative velocity of the two components was very large and therefore the two spectra were very much separated, so as to cause a blurring of the composite spectrum.

The preceding results enable us, with the assistance of micrometer observations, to set a limit to the value of the parallax of *Capella*.

Let a = distance apart of the two components ;
D = distance of *Capella* from the Sun ;
R = mean radius of the Earth's orbit ;
s = maximum angular separation of the two components ;
p = the parallax.

Then $\frac{a}{D} = s$

and $\frac{R}{D} = p$;

Hence ~~for~~ $\frac{a}{R} = \frac{s}{p}$,

or $p = \frac{Rs}{a}$.

If we make $a \sin i = 83{,}000{,}000$ kilometers, and $R = 149{,}000{,}000$ kilometers, we shall have

$$p = \frac{149}{83} s \sin i.$$

Messrs. W. J. Hussey, R. G. Aitken, and C. D. Perrine, of this observatory, report that on the most favorable nights they have been

unable to see any certain elongation of *Capella* with the 36-inch telescope. Consequently it is reasonable to say that s cannot be so great as $0''.06$, for such a separation would certainly be detected if it existed.

If we give sin i its maximum value, unity, we have the relation

$$p < 0''.06 \times \frac{149}{83} = 0''.11.$$

H. M. Reese.

July 25, 1901.

OBSERVATIONS OF THE SPECTRUM OF *NOVA PERSEI*.[1]

At the time of the discovery of *Nova Persei*, the two single-prism spectrographs, with which all our low-dispersion photographs of the past ten years were secured, had just been shipped to Sumatra with the Crocker Eclipse Expedition. This shipment, including likewise several minor pieces of apparatus, left the spectroscopic resources of the observatory temporarily inadequate for the efficient analysis of the star's light. The Mills spectrograph was too powerful for a qualitative study of the spectrum, and was limited in its action to parts of the blue and violet regions. Fortunately, we possess an abundant supply of large 60° prisms, both light and dense; and from these, in connection with the Mills spectrograph, new and efficient apparatus was designed and constructed as required.

In all the spectrographs employed, and described below, the collimator section of the Mills spectrograph was used; and the changes made relate entirely to prism boxes, cameras, and braces for supporting the cameras. It will be a convenience in the discussion of the observations to have some ready method of referring to the different combinations of apparatus.

The Mills spectrograph, as ordinarily employed, will retain its usual designation.

The other instruments, referred to as spectrographs I, II, III, and IV, will now be described.

I. A brass prism box, designed some years ago by Mr. Campbell, for converting the Mills spectrograph into a one-prism instrument, was made ready for use by the evening of February 25. It contained a single 60° light flint prism, and carried the regular Mills camera of 406 mm focal length. The instrument was found to give excellent

[1] From *Lick Observatory Bulletin* No. 8.

definition from above λ 3700 to λ 5700. By tilting the plate slightly, the definition was equally good from λ 4000 to λ 6000.

II. A large 60° dense flint prism, and a visually corrected triple lens of aperture 5 cm and focal length 53 cm, were mounted in wood, and attached to the collimator section of the Mills spectrograph. Most of the visual observations, and some photographs in the yellow and orange regions, were secured with this instrument. It replaced spectrograph I late in the evening of February 25, and visual observations were obtained. The fine dark D sodium lines in the broad bright D band were seen at once, and with ease. The dark lines were compared directly with the bright D lines from an alcohol flame; and the star's lines were estimated by the two observers, respectively, to be displaced to the red about an eighth and a tenth of the distance between D_1 and D_2. These estimates — corresponding to radial velocities of 38 and 30 kilometers per second — were in close agreement with the photographic results [see page 51] secured a few nights later.

III. It was considered very desirable to obtain high-dispersion photographs of the D region. As the Mills spectrograph is limited to portions of the blue and violet, it was necessary to construct another prism box, and some auxiliary apparatus to secure the desired result. A prism box to hold three very dense 60° prisms was constructed of wood by the observatory carpenter, from designs by Mr. Wright. The whole matter of designing, constructing, adjusting, and testing the apparatus required a day and a half. The instrument gave excellent results; no effects of flexure or shrinkage of the wood during the long exposures were visible. With the 406 mm camera, the separation of the D lines is 0.15 mm.

IV. Another box, similar in design to the one described in the preceding paragraph, was constructed for the purpose of photographing the H and K region under high dispersion. It was lighter in some of its parts, and gave evidence of flexure. Results of value were secured with it, however. The three Mills prisms were used in this box, as the denser ones were entirely too yellow for work in the violet.

The comparison lines used include those of iron, magnesium, sodium, hydrogen, and helium. Wave-length determinations have in all cases been based on the Hartmann-Cornu formula.

The spectrum was recorded from $H\delta$ to $H\beta$ on February 24, with

PLATE XII

FIG. 1

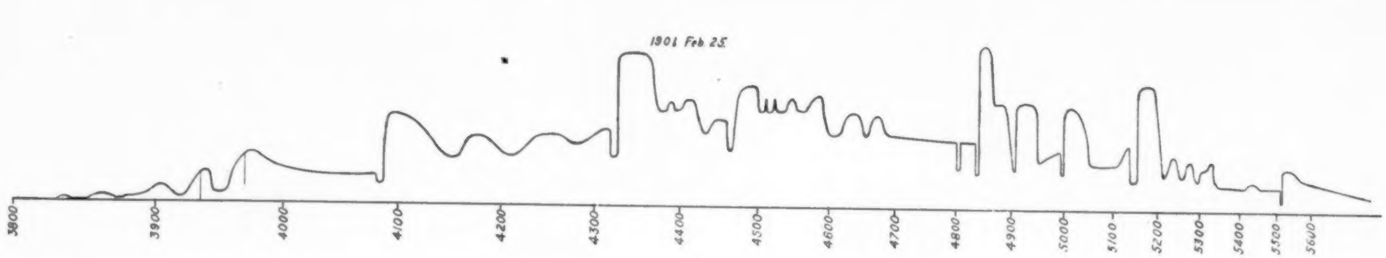


FIG. 2

Fig. 1. — *Nova Persei*, enlarged 7-fold. 1901, February 25.
Fig. 2. — *Nova Persei*, intensity curve. 1901, February 25.

the Mills spectrograph. The $H\delta$, $H\gamma$, and $H\beta$ bands of hydrogen were bright, and extremely broad, and were accompanied on their violet sides by very broad absorption bands. Otherwise the spectrum appeared to be strictly continuous. The absorption in the dark bands was only partial, so that the contrasts between bright and dark bands were very slight. The $H\beta$ bands were easily visible, but the $H\gamma$ and $H\delta$ bands were rather difficult, as a result of the too strong dispersion afforded by this instrument. The general character of the spectrum would have been shown much better by one-prism spectrograms.

On February 25, photographs were secured with spectrograph I, and the star was observed visually with spectrograph II. Numerous bright and dark lines were easily observed; and while allowance must be made for the lower dispersion used, it is safe to say that in the region of the spectrum photographed on the preceding night, the bright bands, and the contrasts between bright and dark bands, were relatively much stronger. The bands appeared to be identical with those in the early spectrum of *Nova Aurigae* (February, 1892), but in the earlier star the bands were much narrower, and the contrasts were vastly stronger.

$H\alpha$ was very bright, and situated with reference to the artificial $H\alpha$ line in the same manner as the other hydrogen bands with reference to their normal positions. It was accompanied on the more refrangible side by its corresponding dark band. A very bright and broad band in the orange, presumably due to sodium radiations, was crossed by two apparently monochromatic dark lines. These were identified as D_1 and D_2. To the violet of this band was the usual absorption. It covered the normal position of D_3, but there is no reason to suspect that it related to the element helium. Besides the five well-known *Nova* bright bands in the region of $\lambda 4860$ to $\lambda 5270$ no further details could be observed visually, on account of the strong continuous spectrum, which masked the fainter bands.

The spectrograms obtained on February 25 extend from $\lambda 3830$ to $\lambda 5700$. One of these, enlarged sevenfold, is reproduced in Plate XII, Fig. 1. Immediately below the reproduction is an intensity curve, Fig. 2, drawn after a comparison of all the plates of the evening. The results of the measurements of two of the plates are contained in Table I.

TABLE I.

February 25.		Description.		
2024 D.	2026 D.			
	λ 3829	Very faint bright band.		
	3840			
	3834.4	Suspected dark line.		
	3851			
	3862	Max. Bright band.		
	3871			
	3917	Minimum of broad absorption band.		
	3933.80	Strong dark line (K).		
	3939	Maximum of bright band.		
	3952	Minimum of broad absorption band.		
	3955	Beginning of bright band.		
λ 3968.54	3968.31	Rather faint dark line (H).		
	3989	End of bright band.		
4078	4081	Slight absorption.		
4086	4087			
	4094	Bright band.		
4141		Bright band.		
4155	4158			
4174	4172	Max. Bright band.		
4198				
	4211	Minimum.		
4217	4218	Bright band.		
4274	4270			
	4277	Minimum.		
4308		Slight maximum.		
4316	4318	Absorption.		
4324	4326			
4335		Max. Bright band.		
4367	4376			
4382		Beginning of bright band.		
4387		Slight maximum.		
4404		Slight maximum.		
4416				
4418		End of band.		
4429		Minimum.		
4432	4442	Maximum.		
4459	4450			
4466		Minimum.		
4470		Maximum double (?).		
4480				
4497		Maximum.		
4510		Very narrow maximum.		These maxima make up a broad band.
4543		Max.		
4555	4553	v. f.		
4569		Max.	Brightening.	
4587	4584	f.		
4591				
4626	4626	Maximum of diffuse bright band.		
4667	4672	Maximum of very faint bright band.		

TABLE I.—*Continued.*

February 25. 2024 D.	February 25. 2026 D.	Description.	
4687	4690	Suspect minimum.	
	4803.0 / 4808.2	Broad absorption line.	
	4833.7 / 4840.6	Broad absorption line.	
4854	4853 / 4905	Max. Bright band.	
	4918	Maximum of bright band.	
	4951	End of bright band.	
	4992.7 / 5000.1	Broad absorption line.	
	5015	Maximum of bright band.	
	5051	End of bright band.	
	5111	Beginning of brightening.	
	5138 / 5152	Absorption band.	
	5179	Maximum of bright band.	These maxima make up a bright band.
	5213.9	Minimum.	
	5231.8	Maximum.	
	5255.1	Minimum.	
	5272.6	Maximum.	
	5294.8	Minimum.	
	5305	Suspect slight maximum.	
	5326	Maximum.	
	5337	End of band.	
	5409 / 5443	Bright band, v. faint.	
	5509	Rather narrow dark line.	
	5511 / 5523 / 5566	Max. Bright band.	

Perhaps the most striking features of the plates are the broad, bright and dark H and K bands, the bright components being crossed by fine dark H and K lines. The band at H is evidently the result of the superposition of the $H\epsilon$ (hydrogen) and H (calcium) bands. The fine H line is apparently not so black as the K line, though allowance must be made for the different densities of the negative at the two places.

The violet edges of the bright bands are the more sharply defined, except for the K band, in which the reverse is the case. The hydrogen bands are very broad and diffuse, and it is difficult to locate the positions of maximum with accuracy. There seems, however, to be a decided shift of the maxima to the violet of the normal positions of

the hydrogen lines, by an amount greater than the probable error of measurement. In the following table the first column contains the normal positions of the hydrogen lines, the second and third the observed positions of maxima taken from Table I, and the fourth the displacement of the maxima in tenth-meters:

λ (normal).	λ in Star.		Δλ.
4102		4094	−8
4341	4335		−6
4862	4853	4853	−9
			−8

The next photographs with the same apparatus were secured on March 15, by which time the spectrum had greatly changed. These changes appear to be more pronounced in the photographs taken on March 18 (Plate XIII), and these two sets will be considered together. The results of the measures are contained in Table II.

TABLE II.

March 13. 2049 C.	March 18. 2057 D.	Description.
λ 3866.79		Narrow dark line.
3869.87	λ 3870.0	Narrow dark line.
3878	3874	
3896	3892	Maximum } Bright band ($H\zeta$).
3912	3910	
3933.89	3933.67	Fine dark line (K).
	3945	Apparent beginning of bright band.
3945.2	3945.7	Fine dark line.
3946.9		Fine dark line.
3950.37	3950.16	Strong dark line. Width in 2057 D = 0.9 t. m.
3968.40	3968.62	Narrow dark line (H).
3974	3975	Maximum of bright band ($H\epsilon$).
3987	3991	End of band.
	4068	Beginning of bright band.
4075.3	4074.6	Dark line.
4078.0	4077.4	Dark line.
4081.35	4081.32	Strong dark line. Width in 2057 D = 1.3 t. m.
4105	4108	Maximum of bright band ($H\delta$).
4128	4131	End of band.
	4171	Maximum of very faint bright band.
	4219	} Very faint bright band.
	4244	

PLATE XIII

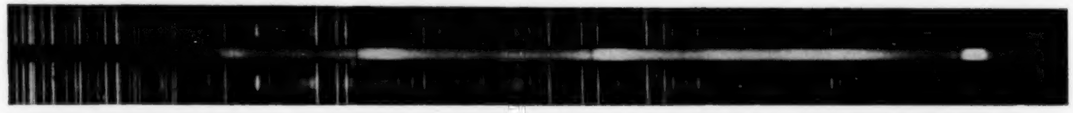


FIG. 3

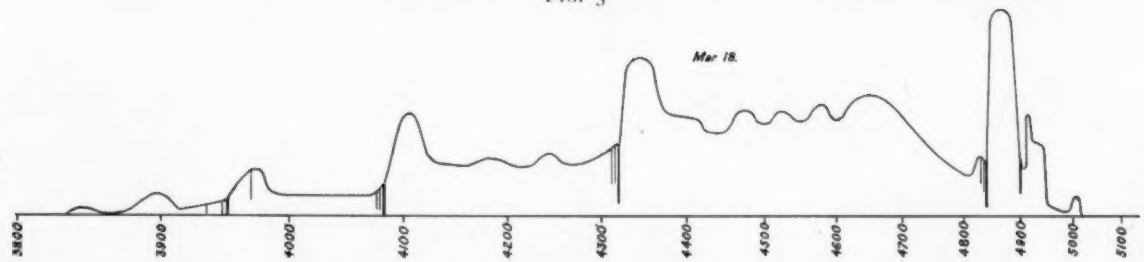


FIG. 4.

Fig. 3.—*Nova Persei*, enlarged 7-fold. 1901, March 18.
Fig. 4.—*Nova Persei*, intensity curve. 1901, March 18.

TABLE II.—*Continued.*

MARCH 13. 2049 C.	MARCH 18. 2057 D.	Description.
	4303	Beginning of bright band.
	4310.2	Faint fine line.
4312.7		Faint fine line (suspected).
4315.0	4314.2	Faint fine line.
4318.42	4318.55	Strong, well-defined dark line. Width in 2057 D = 0.9 t. m.
4342	4347	Maximum of bright band ($H\gamma$).
4366	4368	End of band.
	4454 4490	Very faint and diffuse bright band.
	4515	Maximum of suspected bright band.
	4820	Beginning of bright band.
	4826	First maximum of bright band.
	4828	Suspect dark line.
	4832.7	Faint dark line.
4835.0	4836.5	Strong dark line. Width = 1.9 t. m.
4862	4868	Maximum of bright band ($H\beta$).
4907	4900	Beginning of bright band.
4916	4914	Maximum.
4946	4943	End of band.
5015	5005 ±	Maximum of bright band, just visible.

The spectrograms of March 13 show the K band to have disappeared. Most probably the H band shared a similar fate, though it is impossible to prove this, on account of the superposition of the $H\epsilon$ band referred to above. The fine H and K lines remain, but the absorption in the former appears to be less complete than before. The maxima of the bright hydrogen bands are shifted toward the red from the normal positions of the hydrogen lines. The amount of this shift, taken from Table II, is as follows:

Line.	$\Delta\lambda$.	
	March 13.	March 18.
$H\zeta$	+7 t. m.	+3 t. m.
$H\epsilon$	+4	+5
$H\delta$	+3	+6
$H\gamma$	+1	+6
$H\beta$	+1	+7
(Means)	+3	+5

The bands are so diffuse that the position of maximum in any one case is uncertain to the amount of several tenth-meters. It is certain, however, that there is a displacement in the direction mentioned.

It is in the dark bands accompanying the bright ones that the changes are most marked. The former broad, diffuse absorption bands are replaced by multiple fine lines. Of these lines, the one of greatest wave-length is many times the most intense, and practically terminates the bright band with which it is associated. Two other lines were observed with certainty in many of the groups, and were suspected in all the groups, except $H\zeta$, where the spectrum was too faint for reliable observation.

The displacements of the principal dark lines from the normal positions of the hydrogen lines vary considerably from one end of of the spectrum to the other, but seem to be very approximately proportional to the wave-lengths. In the following table the means of the displacements for the two dates are given in the second column, while those computed on the assumption of direct proportionality to the wave-lengths are given in the third. The assumed proportion is represented by the equation $\Delta\lambda = 0.00505\ \lambda$.

Line.	$\Delta\lambda$.		O—C	Weight.
	Observed.	Computed.		
$H\zeta$	19.28 t. m.	19.64 t. m.	−0.36 t. m.	1
$H\epsilon$	20.04	19.98	+0.06	1
$H\delta$	20.51	20.79	−0.28	1
$H\gamma$	22.18	22.91	+0.27	1
$H\beta$	25.7	24.5	+1.2	½

The wave-lengths in the neighborhood of $H\beta$ cannot be determined with great accuracy from these plates, on account of both the relatively low dispersion in that region of the spectrum, and the unsatisfactory nature of the comparison lines available for measurement. In the determination of the constant of proportionality the $H\beta$ result was therefore given weight one-half. Considering the unsymmetrical distribution of light on the two sides of the absorption lines, it is safe to say the residuals (O—C) are commensurate with the errors of measurement. The proportionality of the displacements of the dark hydrogen lines to their wave-lengths therefore appears to be a fundamental characteristic of the star's spectrum at this stage of its development.

We shall refer to the displacements of some of the other dark lines, the origins of which are open to little doubt. While the dark H and K bands were in evidence, they were displaced toward the more refrangible end of the spectrum by about 16.5 t. m. On account of the breadth of the bands, the measured displacement is liable to an error of perhaps two tenth-meters. The displacement computed by means of the proportionality assumed above is 20 t. m. The displacement of the dark D band (dûe to sodium), which will be referred to below, is 27 t. m. The error of measurement of the position of this band is influenced by its breadth, and to some extent by the sensitiveness curve of the "isochromatic" plate used, which is very steep in this region of the spectrum. The tendency would be to make the measured displacement smaller. The computed displacement is 30 t. m.

The computed displacements given above depend, as has been said, on measurements of the fine hydrogen lines which developed after the calcium bands had disappeared, and probably after the spectrograms of the D band had been secured. It might therefore seem more reasonable to compare the displacements of the calcium and sodium bands with those of the diffuse bands of hydrogen which existed simultaneously with them, and resembled them somewhat in their general characteristics. The displacements of the hydrogen bands are:

Line.	$\Delta\lambda$.
$H\delta$	-19 t. m.
$H\gamma$	-19
$H\beta$	-24

From these we obtain the equation $\Delta\lambda = 0.0046\,\lambda$. The observed displacements, and those computed on this basis, are:

Line.	$\Delta\lambda$.	
	Observed.	Computed.
K	-17 t. m.	-18 t. m.
H	-16	-18
D	-27	-27

The agreement is closer than that resulting from the first assumption. There is then no evidence that the position of the bands is affected by other considerations than that of wave-length.

The other features of the spectrum are shown in the reproduction

of one of the plates of March 18, Plate XIII, Fig. 3, directly enlarged from the original negative; and still better by the intensity curve subjoined Fig. 4.

The drawings of the intensity curves for February 25 and March 18 are not strictly comparable on the red side of $H\beta$, for the reason that the plates used on the two dates were of different character. The earlier spectrogram was made on a Cramer Isochromatic plate, and the late one on an ordinary Cramer Crown, a plate not sensitized to the lower rays. The isochromatic plate is of reduced sensitiveness in the region λ 4800 to λ 5400; and in constructing the intensity curve the observer increased the ordinates in this region somewhat arbitrarily, but in accordance with his judgment. In all of the plates secured on March 13 and 18, the region λ 4600–λ 4700 was over-exposed, and the details thereby destroyed.

During the early part of April the appearance of the spectrum was as is indicated in Plate XIV, Figs. 5 and 6, and in Table III. The triple absorption lines referred to above had so decreased in intensity as to make their recognition very uncertain. A broad and diffuse absorption had developed in the neighborhood of the normal position of the three principal hydrogen lines. $H\zeta$ is just on the limit of visibility on the photographs, and no details can be observed with certainty in that region. The spectrogram of April 5 was made on a Cramer Isochromatic plate, as was also that of February 25, so that the two should be comparable.

It was not possible to observe the star every night over a long period of time, for the purpose of detecting rapid variations in the spectrum: such ones, for instance, as might accompany the more or less periodic changes in the star's brightness. In general, it was noticed during the spring months that the bright bands were relatively more intense at minima than at maxima of the star's brightness; that is, that the variations affected the continuous spectrum more than the bright lines. We recognize that physiological effects may play an important part in such estimates, however. Definite changes certainly occurred between April 1 and 5. The bands λ4629 and λ4675, appearing on the spectrogram of April 5, are not on that of April 1; and the bands of April 1 at λ4583 and $\lambda\lambda$4632–4661 are not recorded on that of April 5. The band at λ4675 was too faint to record itself on the earlier photograph. The changes described could be caused by variations in the relative intensities of one or two of the bands concerned.

PLATE XIV

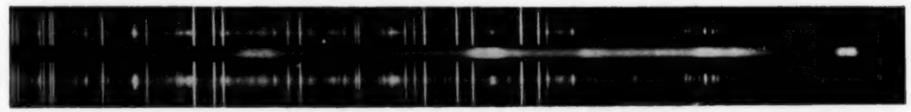


Fig. 5

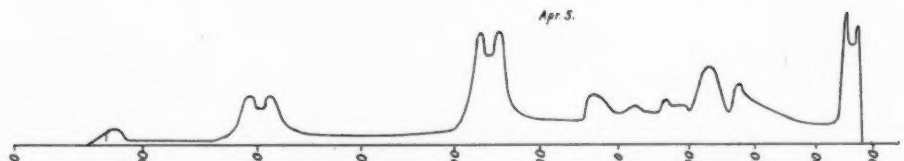


Fig. 6

Fig. 5.—*Nova Persei,* enlarged 7-fold. 1901, April 5.
Fig. 6.—*Nova Persei,* intensity curve. 1901, April 5.

TABLE III.

April 1. 2064 D.	April 5. 2067 D.	Description.
λ 3956	λ 3959	v. f. bright band ($H\epsilon$)
3986	3982	
3968.1	3968.5	Dark line, very poor (H).
4079	4079	Bright band ($H\delta$).
4097	4097	Diffuse absorption, very faint.
4103	4109	
4126	4126	
4318	4317	Bright band ($H\gamma$).
4335	4337	Diffuse absorption, very faint.
4340		
4344	4349	
4365	4368	
4457	4456	Bright band.
	4461	Max.
4492	4489	
	4523	Center of very diffuse bright band.
4508		Suspected v. f. bright band.
4536		
	4555	Maximum of rather faint bright band.
	4562	
4583		Maximum of suspected faint bright band.
	4600	Suspected minimum.
	4607	Bright band. Identical (?)
	4629	Max.
	4660	
4632		Bright band.
4661		
	4667	Bright band.
	4675	Max.
	4683	
4699		Max. of v. f. bright band, just visible.
4847	4837	Bright band ($H\beta$).
	4855	Diffuse absorption, v. f. and uncertain.
	4861	
	4869	
4881	4882	

The absence, in Sumatra, of the principal parts of the large visual spectroscope, prevented visual measurements of the spectrum. There was little need for these, however, as the isochromatic plates afforded vastly more valuable observations down to and including the D region; and the $H\alpha$ band was photographed with erythro plates, as well as observed visually. In February no bright bands were visible except those which have been mentioned above, or described in the tables. As the star grew fainter, additional bands were observed. At

the times of the last visual observations, on April 14 and 21, essentially all the bands observed in the early spectrum of *Nova Aurigae* were present. Those at λ5760, λ5840, λ6160 and λ6300 were easily seen. The last photographic observation was secured on April 14.

The spectrum was observed visually on two evenings, with instrument I, for the purpose of determining whether the light of the star was polarized in any manner. The slit was opened wide, and a Nicol prism was held in front of the eyepiece. As the prism was rotated, no narrowing of the lines, or other phenomena, were observed, except a slight darkening of the spectrum as a whole, due to the polarizing effect of the spectroscope. The results furnish no evidence of a Zeeman effect in the star, but in some respects the evidence is merely of a negative character.

The velocities in the line of sight determined from measurements of the fine dark H and K calcium lines on all the plates secured up to and including March 18, with spectrograph I, are contained in the following table:

Date.	Plate No.	Velocities.	
		H.	K.
February 25...	2023 C	− 4 km	+ 6 km
	2025 C	+ 2	+ 5
	2026 D	....	+ 13
March 13.....	2049 C	− 6	+ 13
	2050 D	+ 22	− 4
March 18.....	2056 C	....	+ 14
	2057 D	+ 7	+ 7
	Means	+ 4.2	+ 7.7

These values are corrected for the orbital motion of the Earth, but not for diurnal motion and the curvature of the spectrum lines. These corrections are − 0.2 km and − 0.3 km respectively. Applying them to the mean of the individual determinations, we have + 5.7 km per second as the observed radial velocity of the star. This value was used in correcting all the wave-lengths determined with spectrograph I.

Recalling that the above individual results depend each upon

PLATE XV

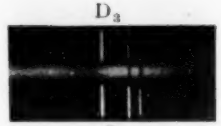


FIG. 7

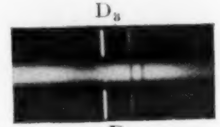


FIG. 8

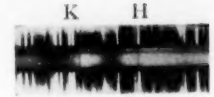


FIG. 9

Fig. 7.—*Nova Persei*, D region, enlarged 8-fold. 1901, February 28.

Fig. 8.—*Nova Persei*, D region, enlarged 8-fold. 1901, March 3.

Fig. 9.—*Nova Persei*, H and K region, enlarged 9-fold. 1901, February 25.

measures of a single line, on plates secured with an instrument containing only one light flint prism, whereas the current results with the Mills spectrograph depend upon measures of many lines dispersed by three dense flint prisms, the linear values of the discrepancies are seen to be small.

A spectrogram of the H and K region secured on March 5 with spectrograph IV yielded the following velocities, from the fine dark lines:

H, + 6.5 km
K, + 8.1

Means, + 7.3

A discrepancy of 2.5 km at $H\gamma$ corresponds in linear value to 1.8 km at H.

These dark lines were very narrow. Their measured widths on the above plate were 0.22 t. m. and 0.28 t. m., respectively, including the effects of flexure of the instrument in broadening the lines.

Plate XV, Fig. 9 is a reproduction of the H and K region recorded with spectrograph I on February 25.

Spectrograms of the D region were secured on February 26, 27, 28, March 3, 14, and 17, with either low or high dispersion. While some of the low dispersion plates are quite satisfactory, those of high dispersion are so much more so, that results from the high dispersion alone will be considered. Two of the latter were obtained on February 28 and March 3. Reproductions of them are given in Plate XV, Figs. 7 and 8, respectively. The position of maximum is apparently to the violet of the D absorption lines; but the slope of the sensitiveness curve of the plate, referred to above, would have a very strong tendency to shift the apparent maximum to the violet, so that it is impossible to locate the actual position of greatest intensity.

The radial velocities of the *Nova* determined from the D lines on these plates are as follows:

Date.	Plate No.	Velocity.		Mean.	Corr. for Curv.	Red. to Sun.	Velocity.
		D_1.	D_2.				
Feb. 28 ..	2034 C	+ 38.7	+ 33.8	+ 36.1	− 2.7	− 27.3	+ 6.1 km
Mar. 3 ..	3040 D	+ 33.8	+ 25.8	+ 29.8	− 2.3	− 27.0	+ 0.5
			Mean velocity with reference to Sun....				+ 3.3 km

In comparing these results for the D region with those secured from ordinary line-of-sight work in the violet region, it is necessary to bear in mind the matter of relative prismatic dispersion for the two regions. In the Mills spectrograph work at $H\gamma$, we should be satisfied if the discrepancy between the values secured from two plates, on each of which only two lines had been measured, were less, say, than 2½ kilometers per second. The linear value of the discrepancy between the above results, $6.1 - 0.5 = 5.6$ km, would correspond to 2.4 km at $H\gamma$ with the Mills spectrograph.

As a check on these results, the D lines were measured on a spectrogram of the planet *Mars*, taken under similar conditions. The difference between the observed and computed velocities, -2.2 km corresponds to -1.0 km at $H\gamma$, and is satisfactory.

The D absorption lines are very narrow. A comparison of their widths with those of the corresponding lines in the solar spectrum is not without interest. A measurement of one of the plates places their width at 0.8 t. m. The width of the solar lines according to Rowland's tables is 0.17 t. m. It was considered better, however, to compare the two spectra under the same instrumental conditions. The widths of the D lines on a spectrogram of *Mars* and on one of the Sun were therefore measured, with the following results:

Line.	*Mars.*	Width in Sun.	*Nova.*
D_1	1.0 t. m.	0.9 t. m.	0.8 t. m.
D_2	1.2	1.1	0.8

The solar and planetary lines are probably somewhat broadened by the presence of unresolved companions, but it is evident that the breadths in the two cases are of the same order. The last spectrogram of the D region, secured in the spring, was a low dispersion one taken on March 17. It showed the general features to have remained practically unchanged.

For convenience, the determinations of radial velocity referred to above are here collected:

Spectrograph I, H and K, $+5.7$ km
Spectrograph III, D_1 and D_2, $+3.3$
Spectrograph IV, H and K, $+7.3$

In addition to the spectrograms on which these results depend, a number of others recorded the absorption lines of sodium and

PLATE XVI

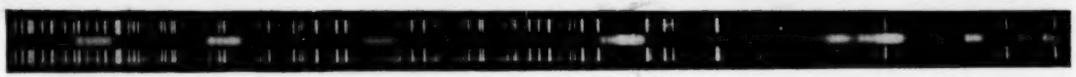


Fig. 10

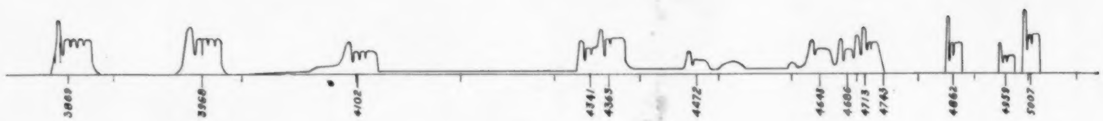


Fig. 11

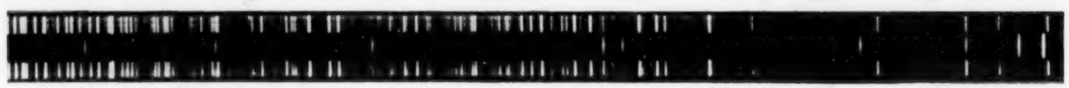


Fig. 12

Fig. 10.—*Nova Persei*, enlarged 7-fold. 1901, July 15.
Fig. 11.—*Nova Persei*, intensity curve. 1901, July 15.
Fig. 12—*N. G. C.* 7027, enlarged 7-fold. 1901.

calcium. Within the limits of error of measurement, all give accordant results. There is no evidence that the velocity is variable; and this view is strongly confirmed by the results of the summer series of observations, to be described below.

Spectroscopic observations of *Nova Persei* were discontinued from April 21 to July 9, while the Sun was passing through this region of the sky. Our regret that the southern position of the Lick Observatory prevented observations in this period is coupled with the hope that the observatories of northern Europe were able to obtain a practically continuous series.

Our summer series of observations has been secured mainly with spectrograph I. The first observation of the series was made on July 9. As announced by Professor Pickering, the spectrum at this time was that of a nebula. The usual nebular lines are represented by broad bright bands. The several spectrograms obtained at well-distributed intervals since July 9 do not show that any pronounced changes have occurred in this time. The results of the measurements of four of the plates are contained in Table IV. An ordinary plate, No. 2198 C of July 15, and an isochromatic plate, No. 2223 D of August 11, with their corresponding intensity curves, are reproduced in Plate XVI, Figs. 10, 11, 13, and 14, respectively.

TABLE IV.

July 15. 2198 C.	July 16. 2199 D.	July 24. 2205 E.	August 11. 2223 D.	Description.
λ 3855	....	λ 3854	....	Beginning of bright band.
3858.3	....	3858.3	....	Absorption line.
3860.3	....	3860.1	....	Maximum of bright band.
3864.0	....	3864.2	....	Broad absorption line.
3869.7	....	3869.7	....	Broad and hazy absorption line.
3874.9	....	3875.0	....	Absorption line.
3878.9	....	3879.0	....	Absorption line.
3885	....	3885	....	End of brighter part of band.
....	....	3890	....	End of band.
....	....	3947	....	Beginning of bright band.
3953	....	3953	....	Beginning of brighter part of band.
3959.1	....	3959.0	....	Maximum of bright band.
3962.6	....	3962.8	....	Broad absorption line.
3968.64	....	3968.71	....	Strong and narrow absorption line (H).
3971.4	....	....	....	Suspect absorption line.
3984	....	3984	....	End of brighter part of band.
....	....	3988	....	End of band.
....	....	4056	....	Beginning of brightening.
4088	....	4084	....	Beginning of brighter part of band.

TABLE IV.—*Continued.*

July 15. 2198 C.	July 16. 2199 D.	July 24. 2205 E.	August 11. 2223 D.	Description.
4093.5	....	4093.9	....	Maximum of bright band.
4097.1	....	4097.2	....	Rather broad absorption line.
....	....	4108.5	....	Absorption line.
4118	....	4120	....	End of band.
4325	....	4324	....	Beginning of bright band.
4331.5	....	4330.9	....	First maximum.
4335.5	....	....	....	Rather narrow dark line, absorption incomplete.
4349	....	4348	....	Beginning of second brightening.
4353.2	....	4353.9	....	Second maximum.
4357.9	....	4358.2	....	Absorption line.
4364.6	....	4364.7	....	Diffuse absorption line.
4385	....	4381	....	End of brighter part of band.
		4390	....	End of band.
4456	....	4455	....	Beginning of bright band.
4462	....	4462.0	....	Maximum.
4466	....	4467.1	....	Absorption line.
....	....	4472.1	....	Suspect absorption.
4488	....	4489	....	End of band.
4497	....	4499	....	Beginning of faint diffuse bright band.
4523	....	....	....	Diffuse maximum.
4548	....	4549	....	End of band.
4557	....	....	....	Beginning of suspected faint band.
4561	....	4559	....	Maximum.
4568	....	....	....	End of band.
4590	....	4594	....	Beginning of faint brightening.
....	....	4600	....	Maximum.
4613	....	4609	....	End of brightening.
4615	....	4618	....	Beginning of bright band.
4623	....	....	....	Suspect faint maximum.
4632	....	....	λ 4631.2	Principal maximum.
4635	....	....	4633.8	Absorption line.
4661	....	4656	4656	End of band.
4669	....	4670	....	Beginning of bright band.
4676	....	4675.5	4675.4	First maximum.
4681	....	4680.5	4680.6	Absorption line.
4689	....	....	4687.0	Absorption line.
4696	....	4695.7	....	Absorption line.
4698	....	4698	4698.1	Beginning of what is evidently a superposed band.
4703	....	4702.3	4703.0	Second maximum.
4708	....	4707.9	4708.7	Hazy absorption line.
4714	....	4713.2	4713.8	Third maximum, stronger than preceding ones.
....	....	4717.8	4719.5	Absorption line.
....	....	....	4725.7	Absorption line.
4736	....	....	....	Absorption line.
4748	....	4745	4742	End of band.
4845	....	4846	4846	Beginning of band.
4849	....	....	....	Absorption line.
4852	....	4853.2	4850.0	Maximum.
4856	....	4855.7	4854.8	Absorption line.

TABLE IV.—*Continued.*

July 15. 2198 C.	July 16. 2199 D.	July 24. 2205 E.	August 11. 2223 D.	Description.
4862	....	4862.7	4862.1	Absorption line.
4869	....	....	4868.4	Absorption line.
4873	....	....	....	Suspect absorption line.
4880	....	4879	4878	End of band.
4945	....	4944	4942	Beginning of bright band.
4948	....	4947.7	4946.8	Maximum.
4954	....	4952.2	4952.6	Absorption line.
4961	....	4960.3	4959.0	Absorption line.
4968	....	....	4966	Suspect absorption line.
4976	....	4979	4978	End of band.
4989	....	4990	4987	Beginning of bright band.
4992	....	....	....	Suspect absorption line.
4996	....	4995.4	4994	Maximum of bright band.
5001	....	5000.6	....	Absorption line.
5008	....	5008.2	....	Absorption line.
5016	....	....	....	Suspect absorption line.
5027	....	5026	5027	End of band.
....	λ 5038	....	....	Absorption line.
....	5040	....	5039	
....	5049	....	....	maximum — Faint bright band,[1] which possibly runs back to preceding band.
....	5067	....	5070	
....	5136	....	5137	
....	....	....	5168	maximum — Bright band.[1]
....	5201	....	5199	
....	5264	....	5259	
....	5297	....	5298	maximum — Bright band.[1]
....	5312	....	5317	
....	5389	....	5393	
....	5414	....	....	maximum — Bright band.[1]
....	5433	....	5438	
....	5513	....	5513	Difficult bright band.[1]
....	5548	....	5562	
....	....	....	5603	Maximum of very difficult bright band, broad and diffuse.[1]
....	5652	....	5651	
....	5671	....	....	maximum — Bright band.[1]
....	5713	....	5716	
....	5733	....	5735	Beginning of bright band.
....	5741	....	5741	Maximum.
....	5746	....	5747	Absorption line.
....	....	....	5764	Suspect absorption line.
....	5769	....	5770	Absorption line.
....	5778	....	5776	End of band.
....	5856	....	5857	Beginning of bright band.
....	5863	....	5862	Maximum.
....	5869	....	5867	Absorption line.
....	5877	....	5878	Absorption line.
....	5890	....	5890	Absorption line (D_2).
....	....	....	5895	Absorption line (D_1).
....	5896	....	5896	End of band.

[1] These bands are very diffuse. The determinations of wave-length are therefore uncertain to the extent of several tenth-meters.

The *Hα* band is very bright, but no other details additional to those on the photographs have been shown by the visual observations.

A striking feature of the spectrum is the distribution of the light in most of the bands. In general, there is a maximum, considerably displaced to the violet of the normal position of the nebular line. This maximum is accompanied on its less refrangible side by a pronounced minimum. In most cases another minimum appears to the red of this, and in some of the bands there are additional minima. The one nearest to the maximum is in each case the strongest. While we have, of course, no knowledge as to the origin of these minima, their appearance certainly suggests that they are absorption phenomena, and they will be referred to as such. Though most of the bands conform to a general type, they are not by any means duplicates of one another. In some cases the principal absorption line alone was identified with certainty, while in others lines apparently not belonging to the series were strongly suspected. In a number of instances the appearance of the bands was indicative of such complexity of structure as to make it impossible to consider more than their general features in a preliminary study of this sort. It is quite possible that some of the absorption lines are due to gases in the atmosphere of the star which are not directly involved in the production of the bands. In fact, this actually occurs in the case of the D sodium lines and the H calcium line. The latter appears as an absorption line in the band λ 3947–λ 3988. There is little reason to doubt that its companion, the K line, is absent only by reason of the fact that there the calcium vapor has nothing to absorb.

Another cause of complexity is the overlapping of bands. This occurs in at least three cases:

1. The bands corresponding to λ 4340.6 (*Hγ*) and λ 4363 (nebular line) are involved in the composite band λ 4325–λ 4385.

2. Those belonging to the nebular lines λ 4685.9 and λ 4713.2 (helium) are superposed in the band λ 4669–λ 4746. There are, in fact, circumstances which indicate the presence of still another component in this band. It will be seen by referring to Table IV that there is a maximum at λ 4714, brighter than the one at λ 4703, and which cannot be accounted for by the superposition of the two bands to which reference has been made, assuming them to be of normal type. In addition, there are absorption lines at λ 4719 and λ 4725.7. These effects would be produced by a superposed band of the regular

type corresponding to a line of normal wave-length λ 4724. Moreover, judging from the other bands, the band whose maximum is at λ 4703 should vanish at about λ 4733, whereas the composite band in question extends to λ 4746. The extension may, however, be due to the nebular line λ 4743 $\pm$, the presence of which is partially indicated by an absorption line at λ 4736. While the complexity of the band is such that a final statement of its composition is impossible without further study, the hypothesis of a line normally at λ 4724 is advanced as furnishing a plausible explanation of the structure of the broad band.

3. The band λ 3953–λ 3984 was supposed at first to be the broadened $H\epsilon$ line; but on this supposition the line is unduly strong. The $H\gamma$ band is very bright, $H\delta$ is fairly bright, and the λ 3969 is very bright, whereas $H\zeta$ and the rest of the ultra-violet hydrogen series do not appear. Furthermore, the displacement of the maximum of this band to the violet of the normal position of $H\epsilon$ was greater by about two tenth-meters than that of the other maxima in this region of the spectrum. Some spectrograms of well-known planetary nebulæ recently secured by Mr. Wright fully explain these peculiarities. In all previous work on the nebulæ, the line recorded at this point in the spectrum has been regarded as single, and has been assumed to be $H\epsilon$. The line is in reality a wide double, as shown in the reproduction of the spectrum of *N. G. C.* 7027, Fig. 12. The component of greater wave-length is the $H\epsilon$ hydrogen line at λ 3970.2; it is very faint. The more refrangible component, at λ 3967.6, is much the brighter of the two, and appears to be a characteristic strong nebular line, not previously observed. The positions and relative intensities of these lines leave no doubt that the *Nova* band at λ 3453–λ 3984 corresponds almost entirely to this nebular line at λ 3967.6, and is scarcely influenced by the $H\epsilon$ radiations.

In order to investigate the displacements of the maxima of the star bands, from the normal positions of the lines in the nebulæ, it was found necessary to make more accurate determinations of the wave-lengths of some of the nebular lines than were available. An investigation with that end in view was therefore undertaken by Mr. Wright, and some of the preliminary results will be used in this paper. The following table gives the displacements of the maxima and of the absorption lines of all the bands of the *Nova* which have been identified as being of nebular origin. The first column contains the normal

wave-lengths of the lines in nebular spectra, the second the displacements of the maxima, and the third the computed displacements on the assumption of proportionality of displacement to wave-length, according to the empirical formula $\Delta\lambda = -0.00212\,\lambda$. The following four columns contain the measured displacements of the absorption lines which appear to belong to the bands. Positive and negative signs indicate displacements toward the red and violet ends of the spectrum, respectively. Both the maxima and the minima appear to be displaced in proportion to their wave-lengths. The observed widths of the bands are given in the eighth column, as far as they can be determined; but it should be said that the photographic widths are affected both by their intensities and by the sensitiveness curve of the plate. The red edge of the band at λ 5876 is practically at the limit for isochromatic plates. The wave-lengths of the principal bright bands observed in *Nova Aurigae* in August, 1892 by Mr. Campbell are contained in the last column. That star was of 10.5 magnitude, and the photographs did not cover the ultra-violet regions.

TABLE V.

Wave-lengths in the Nebulæ.	Displacements.						Width of Bands.	Principal Bands *Nova Aurigae*.
	Max. Observed.	Max. Computed.	Min. Observed.	Min. Observed.	Min. Observed.	Min. Observed.		
3868.9	− 8.7	− 8.2	−4.8	+0.8	+6.0	+10.0	31	....
3967.6	− 8.6	− 8.4	−4.9	+1.1*	(+3.8)	.....	31	....
4101.9	− 8.2	− 8.7	−4.8	+1	+7	......	36	4098
4340.6	− 9.4	− 9.2	−5	......	......	......	..	4336
4363.3	− 9.7	− 9.1	−5.2	+1.4	......	......	33	4358
4471.6	− 9.6	− 9.5	−5	(0)	......	......	34	4466
4643±	−11	−10	−8	......	......	......	..	4630
4685.9	−10	−10	−5	+3	......	+10	..	4681
4713.2	−10	−10	−5	......	......	......	..	471—
4743	......	......	−6	......	......	......	..	....
4861.5	− 9	−10	−6	+1	(+7)	(+11)	33	4857
4959.0	−11	−11	−6	+2	......	......	34	4953
5007.0	−11	−11	−6	+1	......	......	38	5002
5752	−11	−12	−6	......	......	+16	43	5750
5875.9	−13	−12	−7	+1	......	......	40	....
6563†	......	......	......	......	......	......	..	....

* The dark line H falls in this place and determines the exact position measured.

† The very bright *Hα* band was observed visually, but no attempt was made to photograph it in the summer series.

Parentheses indicate that the line was only suspected. The absorption in most of the lines is incomplete, so that the bringing out of any

particular one is largely a matter of exposure and development. It is quite possible that other lines exist which will appear in a final comparison of all the spectrograms secured.

The nebular character of the *Nova* spectrum at present is evident from the measures published in the tables, and may be seen at a glance by comparing Plate XVI, Figs. 10, 11, and 12. All of the principal bands correspond to lines known to exist in the nebulæ.

A comparison of the first and last columns of Table V shows that the spectrum of *Nova Aurigae* is very closely related to that of *Nova Persei.* The absence of the bands at λ 4743, λ 5876, and λ 6563 from the former star is no doubt explained by the fact that it was more than four magnitudes fainter than the present star; and it is probable that the bands at λ 3869 and λ 3968 were not recorded in 1892 because no auxiliary correcting lens was used to eliminate the chromatic aberration effects of the 36-inch objective. The bands in the present *Nova* are vastly wider than in that of 1892, and the distribution of light within the bands seems to be different. The positions of corresponding maxima differ about five or six tenth-meters in the two cases. Perhaps the most remarkable features of the 1892 spectrum were the bands observed by Mr. Campbell at λ 4358 and λ 5750. The λ 4358 band, in August, 1892, was estimated to be at least eight times as bright as the $H\gamma$ band; but in November, 1894 it had become fainter than $H\gamma$; and the band at λ 5750, so easily observed in 1892, had become extremely difficult in 1894 (ASTROPHYSICAL JOURNAL, 1, 49–51). These two bands are now very prominent in *Nova Persei*, and it is probable that they will diminish in brightness, as in the case of the earlier star. Corresponding to these two bands there are faint lines in the well-known nebulæ.

The radial velocity of *Nova Persei*, determined from the H absorption line of calcium, was + 6 km on July 15, and + 12 km on July 24. The mean of the two determinations is in satisfactory agreement with the value, 5 km, afforded by the H line in the spring series.

At the time of the spring observations the D absorption lines occupied positions near the middle of the broad D bright band, as shown in Figs. 7 and 8; and the D_3 comparison fell near the more refrangible edge of the band. In the summer observations, the D_3 comparison line, Fig. 13, falls near the middle of the bright band, and the sodium comparison lines are situated at the extreme red edge of the band. A long exposure made on August 12 records this bright

band to about the wave-length λ 5902, and the sodium D absorption lines are clearly shown to be present. Within the limits of error of measurement they occupy exactly the same positions as in the spring observations. Corroborative evidence is thereby afforded that the radial velocity of *Nova Persei* has been practically constant.

It is well known, from the investigations of Runge and Paschen (ASTROPHYSICAL JOURNAL, **3**, 4), and others, that the spectrum of helium consists of two sets of lines, and that the relative intensity of the two sets varies with the pressure to which the radiating gas is subjected. Both sets are emitted by a Plücker tube under a few millimeters pressure. The first column of the following table gives the wave-lengths of all the helium lines between λ 3800 and λ 5900 described by Runge and Paschen as having an intensity equal to or greater than three on a scale of ten. The second column records the intensity. In the third column the Roman numeral I or II indicates that the line belongs to the low or high-pressure series, as the case may be. Each of the sets I and II is subdivided by Runge and Paschen into a principal, a first subordinate, and a second subordinate series. The two subordinate series are indicated by subscripts. The fourth column is self-explanatory.

λ.	Intensity.	Series.	Remarks.
3819.8	4	II_1	Not observed in *Nova*.
3888.8	10	II	Not observed in *Nova*.
3964.9	4	I	Conflicts with band λ 3855–λ 3885, but probably not in *Nova*.
4026.3	5	II_1	Not observed in *Nova*.
4120.9	3	II_2	Not observed in *Nova*.
4388.1	3	I_1	Not observed in *Nova*.
4471.6	6	II_1	Observed in *Nova*, fairly bright.
4713.2	3	II_2	Observed in *Nova*, bright.
4922.1	4	I_1	Not observed in *Nova*.
5015.7	6	I	Not observed in *Nova*.
5875.9	10	II_1	Observed in *Nova*, very bright.

It will be seen that the high-pressure series is the only one appearing in the new star, and that even of this series the more refrangible lines are lacking. The maximum of the line λ 3888.8 should lie just within the band λ 3855–λ 3885; but the helium band should extend to λ 3904 if it were present in any strength. It is a significant fact that both sets are present in most of the nebluæ, though their relative intensities vary considerably. The evidence of the helium lines would

PLATE XVII

FIG. 13

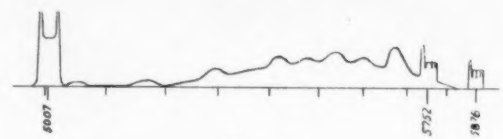


FIG. 14

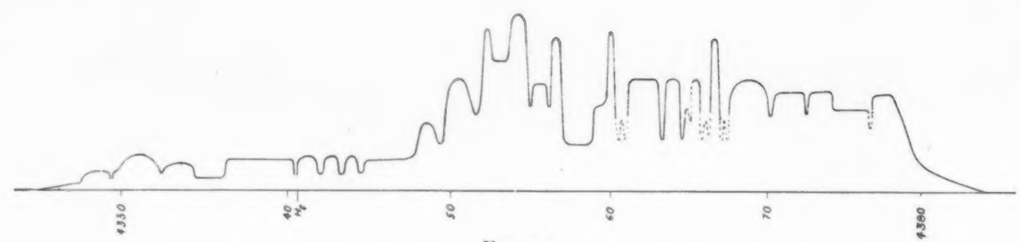


FIG. 15

Fig. 13.—*Nova Persei*, enlarged 8-fold. 1901, August 11.
Fig. 14.—*Nova Persei*, intensity curve. 1901, August 11.
Fig. 15.—*Nova Persei*, $H\gamma$ region, high dispersion. 1901, September 3.

seem to show that the radiation does not take place under exceedingly low pressure.

A number of the bands have recently been photographed with a dispersion of three dense flint prisms. An intensity curve sketched from a Mills spectrogram of a composite band at λ 435 is reproduced in Plate XVII, Fig. 15, and the wave-lengths of the prominent features are given in the following table:

TABLE VI.

Sept. 9 2265 *D*.	Description.	Sept. 9 2265 *D*.	Description.
λ 4324	Beginning of bright band	λ 4355.0	Slight minimum or dark line.
26.3	Suspect dark line.	56.2	Slight minimum or dark line.
28	Beginning of brighter part of band.	57.0	Broad minimum.
		59.0	
28.7	Slight maximum.	60.03	Narrow maximum.
29.32	Absorption line.	60.49	Double dark line.
31.0	Chief maximum of $H\gamma$ band.	60.92	
32.3	Slightly broadened dark line, or minimum.	63.24	Diffuse dark line.
		63.9	Maximum.
33.5	Maximum.	64.53	Dark line.
34.5	Broad minimum.	65.0	Suspect dark line.
36.2		65.4	Maximum.
40.49	Narrow dark line.	65.8	Double dark line.
41.8	Dark line, broader than preceding.	66.3	
41.98		66.6	Maximum.
42.2		67.4	Dark line (possibly double, separated by about the same amount as preceding).
43.3	Dark line, broad and diffuse.		
44.5	Dark line, broad and diffuse.		
47.2	Beginning of brightening, due to λ 4363 band.	68.9	Broad and inconspicuous maximum.
48.5	Maximum.		
49.3	Minimum.	70.2	Diffuse minimum.
50.5	Maximum.	72.45	Narrow dark line.
51.4	Diffuse minimum.	74	Faint minimum.
52.3	Maximum.	77	
53.1	Faint minimum.	4382	End of band.
54.2	Principal maximum of band.		

The bands at λλ 3968, 3441, 4363, 4724, 4861, 4959, 5007, and 5752 have been photographed under high dispersion. They all appear to have the same general features, as follows: A pronounced maximum is near the violet edge of the band, flanked on either side by a subordinate maximum. To the red of this group is a broad minimum, or absorption line, while still farther to the red is a group of maxima and minima giving the appearance of four absorption lines. With low dispersion this group was observed in most of the bands as a broad

and diffuse absorption line (see Table V, column 5). Further than to note these general characteristics, the spectrograms referred to have not been studied.

The bearing of the foregoing observations upon the various theories of new stars is reserved for a future paper.

It is greatly to be regretted that the delicate details of the original negatives are so largely lost in the reproductions.

Acknowledgments are due to Dr. H. M. Reese for assistance in taking many of the photographs and in reducing some of the measures.

W. W. Campbell,
W. H. Wright.

September 12, 1901.

NOTE ON THE SPECTRUM OF *NOVA PERSEI*.

At the request of the Director, and with the assistance of Fellow R. H. Curtiss, I secured several spectrograms of *Nova Persei* with the Crossley reflector during September. The spectrograph used was the small one designed by the late Director Keeler. It has been modified by Fellow H. K. Palmer to receive a prism and lenses of quartz, and has been extensively used by him.

On the plates taken are the nine bands observed between λ 387 and λ 501 by Messrs. Campbell and Wright. In addition to these are two bright bands far up in the ultra-violet. The provisional wave-lengths of these new bands are λ 346 and λ 339. The one at λ 346 is very bright, being surpassed on these plates only by the band at λ 387. It is brighter than the band at λ 397, even though the latter is in a region of greater sensitiveness for ordinary dry plates, and the light of the latter is not so strongly absorbed by the Earth's atmosphere.

The new band at λ 339 is fainter than the integrated bands near λ 471, but stronger than the band at λ 464.

The band at λ 346 coincides in position with a line which Mr. Palmer has discovered in some of the well-known nebulæ during the past summer. This strengthens the conclusion that the spectrum of the *Nova* is nebular. It is probable that the band at λ 339 corresponds to an undiscovered nebular line.

After these results were secured, Professor Max Wolf's article in the *Astronomische Nachrichten*, No. 3736, arrived at Mt. Hamilton. His observations demonstrate, without need of further proof, that the recently reported halo around the *Nova* is purely of instrumental

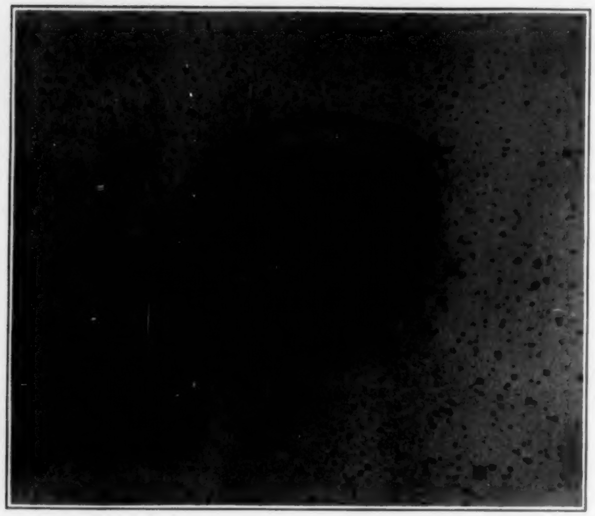


FIG. 1.—PHOTOGRAPH MADE WITH TWO-FOOT REFLECTOR.
Exposure $3^h\ 50^m$.

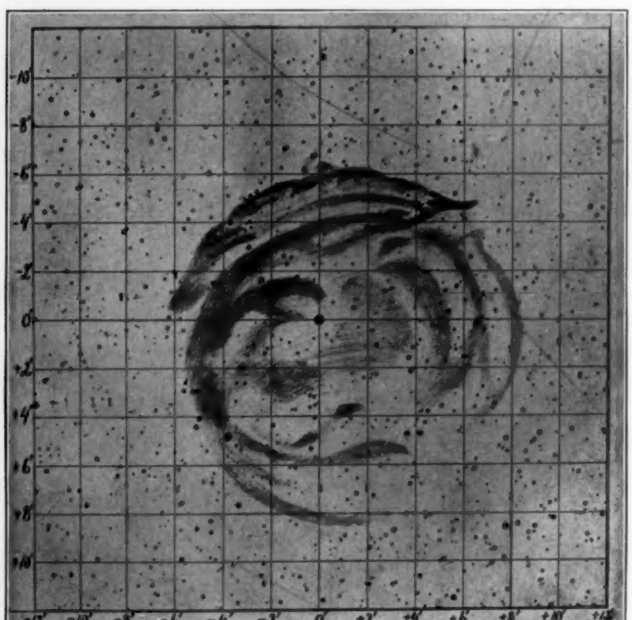


FIG. 2.—DIAGRAM FROM ORIGINAL NEGATIVE.

NEBULOSITY AROUND *NOVA PERSEI*, Sept. 20, 1901.

By G. W. RITCHEY, Yerkes Observatory.

PLATE XIX.

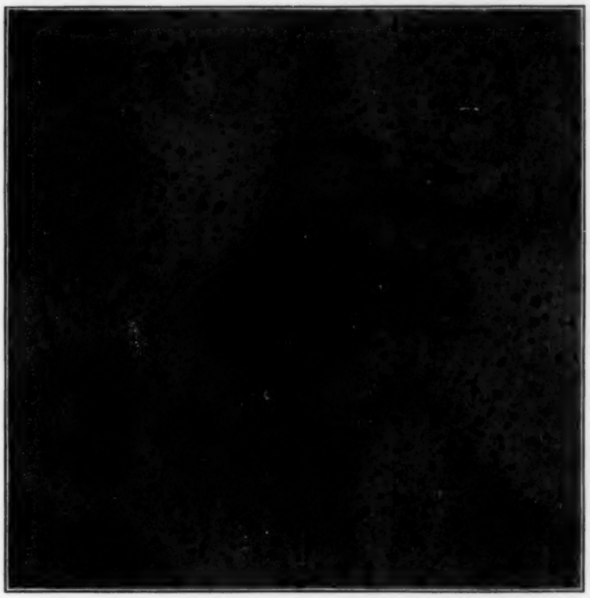


FIG. I.—PHOTOGRAPH MADE WITH TWO-FOOT REFLECTOR.
Exposure 7^h.

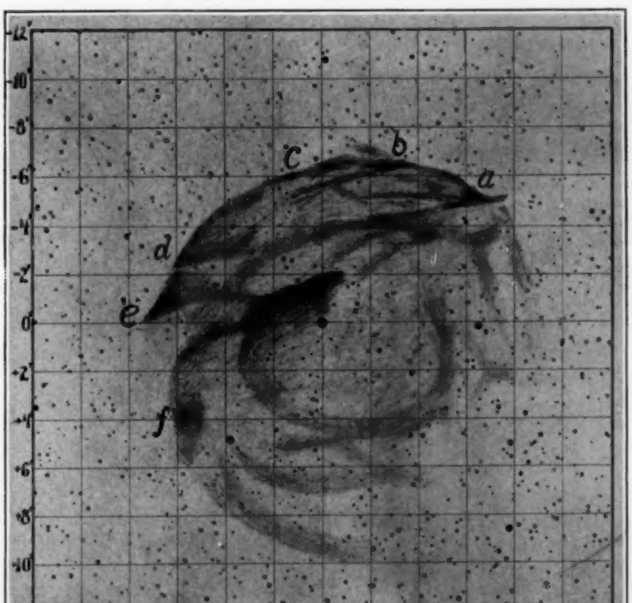


FIG. 2.—DIAGRAM FROM ORIGINAL NEGATIVE.

NEBULOSITY AROUND *NOVA PERSEI*, Nov. 13, 1901.
By G. W. RITCHEY, Yerkes Observatory.

origin. It is undoubtedly true that the chromatic aberration effect, thus observed by Professor Wolf, is due to the ultra-violet bands described above, and especially to the band at λ 346. Professor Wolf's objectives seem to be very transparent, as is shown by the fact that these radiations were able to pass through them at all. His objective *b* evidently transmits them more freely than does objective *a*. If the halo were due to the band at D_3 it should be of practically the same intensity with both objectives.

JOEL STEBBINS.

SEPTEMBER 23, 1901.

CHANGES IN THE NEBULOSITY ABOUT *NOVA PERSEI.*

ON the evening of November 9, 1901, a second photograph of the nebula about *Nova Persei* was secured with the two-foot reflector, but the exposure was cut off by clouds after 90 minutes' exposure had been secured. This negative was immediately developed and examined, and although very weak, the principal condensations of nebulosity were sufficiently strong to show, at the first glance, without the aid of a magnifying glass, that a large change had taken place in the shape of the nebula. The negative was then intensified, and much faint structure was brought out which had been invisible before. It was now certain that the entire southern half of the nebula had been expanding rapidly and nearly radially. On November 11 a telegram was received from Professor Pickering, announcing Perrine's independent discovery of motion in the nebula.

On November 13 a strong negative with seven hours' exposure was secured. The conclusions drawn from the negative of November 9 were all confirmed. Incidentally it was shown that intensification of a weak negative is entirely safe and legitimate; for the details shown on the intensified negative of one and-half hours exposure agree perfectly, so far as they are shown at all, with those in the negative of seven hours exposure.

Eightfold enlargements of the negatives of September 20 and November 13 were now prepared (in triplicate to make certain that no false details were introduced), and preliminary measurements of the positions of the six principal condensations of the nebula, on each of the two negatives, were made, with a scale and protractor, by means of these enlargements.

The results are as follows: *a* is the principal condensation of the

ring, and *b*, *c*, *d*, etc., follow in order of position angle. The negatives of September 20, November 9, and November 13 are designated Neg. 1, Neg. 2, Neg. 3, respectively.

	DISTANCE FROM NOVA.			POS. ANGLE WITH REFERENCE TO NOVA.		
	Neg. 1.	Neg. 3.	Difference.	Neg. 1.	Neg. 3.	Difference.
Condensation *a*..	430″	497″	+67″	133°	129°	− 4°
" *b*..	374	420	+46	167	155	− 8
" *c*..	346	381	+35	202	192	−10
" *d*..	350	395	+45	244	247	+ 3
" *e*..	371	427	+56	263	266	+ 3
" *f*..	366	378	+12	308	304	− 4

In the case of the condensations *a*, *b*, *c*, and *f*, the centers of the condensations were used for the measures, but in the two wing-shaped condensations *d* and *e* it was impossible to decide upon any definite center; consequently the well-defined apex or outer extremity was used in the case of each of these condensations. This may perhaps account for the fact that the change of position angle of these two condensations is positive, instead of negative, as in the others. Photographic copies, and also drawings, of the negatives of September 20 and November 13 are shown in Plates XVIII and XIX.

A comparison of the intensities of the condensations on negatives 1 and 3 shows that the outer parts of the nebula are rapidly fading. On the other hand, the tongue of nebulosity, apparently issuing from the south side of the *Nova*, and curving immediately to the west, is stronger on negative 2, exposed for one and one-half hours, than on negative 1, exposed for nearly four hours; on negatives 2 and 3 this tongue is by far the strongest part of the nebula. This great change of intensity renders it a difficult matter to arrive at a definite conclusion in regard to any change of shape or position of this tongue. Such changes will be carefully watched for in the future; this tongue is so strong that it can be photographed well with the two-foot reflector with an exposure of one and one-half or two hours.

G. W. Ritchey.

Yerkes Observatory,
November 15, 1901.

ERRATA.

In Professor Barnard's article, Astrophysical Journal, Vol. XIV, No. 3, October, 1901, page 153, line 19, *for* a bright spot *read* a black spot.

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In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed. If a request is sent *with the manuscript* one hundred reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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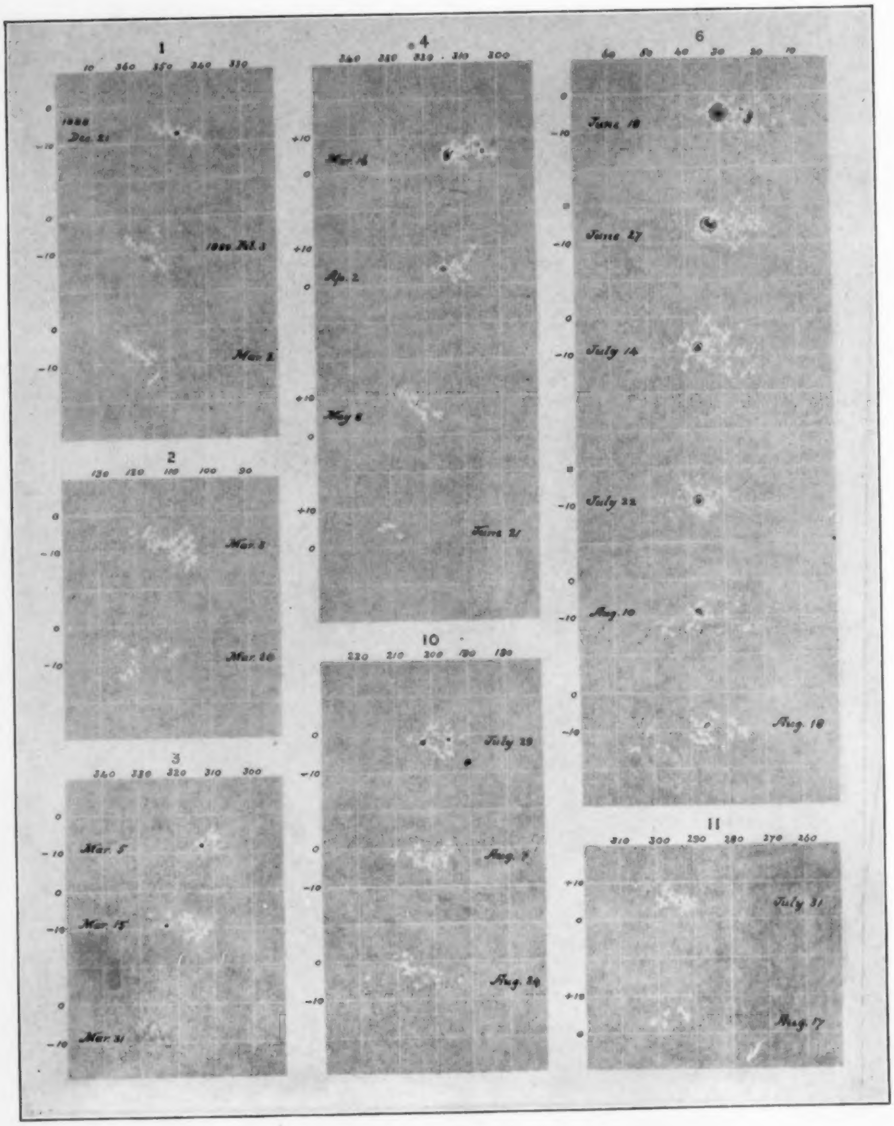
PLATE XX.



DRIFT OF FACULÆ IN LONGITUDE.